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B.S., Naval Engineering
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Investigation of the Plastic Behavior of Fully Clamped Rectangular Plates Under Dynamic Loading

by

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ABSTRACT

The objective of this thesis was an experimental investigation of the plastic behavior of fully-clamped rectangular plates under dynamic loading. Previous experimental work of this subject has included the investigation of the plastic behavior of beams, plates, cylindrical and spherical shells of different materials, thicknesses, and boundary conditions. Specifically, previous examination of fully-clamped rectangular plates has utilized thickness changes for only one aspect ratio. The reasonable expansion of this work is this comparison of different aspect ratios.

The basis of this comparison was the testing of fully-clamped rectangular plates of four aspect ratios: 1.0, .75, .50, and .25 of hot-rolled mild steel (a strain-rate sensitive material), and aluminum 6061-T6 (which is not strain-rate sensitive) through the dynamic loading of a controlled explosion. All tests conformed with established procedures using the explosive DETASHEET, electric blasting caps for detonation, and the MIT explosive test chamber. Plate deflections were measured and the results illustrated by the comparative plots of a non-dimensional variable (deflection/thickness) versus several parameters which are functions of the dynamic energy imparted to the material, the mechanical properties of the material, and the aspect ratio. These

results indicate the dependence of steel on strain-rate sensitivity, and the correlation of theoretical predictions.

Presented in this manner, this information should be very useful to an engineer who might wish to calculate the damage to flat plates subjected to large dynamic loads.

Thesis Advisor: Norman Jones
Title: Associate Professor of Naval Architecture and Marine Engineering

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ACKNOWLEDGEMENTS

I would like to extend my appreciation to all of the people who have helped me with the completion of this investigation.

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With the qualified supervision of Dr. Norman Jones, Associate Professor of Naval Architecture; and my good friend Julio Giannotti, I was always able to take each step as it came.

Throughout the project, Mr. Oscar Wallin and Mr. Fred Merlis were always ready with the experience and know-how to cope with the problems that arose.

Lastly, any credit that I could claim, belongs to the girl who typed this thesis and put up with so much, Miss Donna DeCosta.

NOTATION

B		semi-width of specimen (inch)
H		plate thickness
I'	=	$V_o\sqrt{\left(\left\{\dfrac{\rho B^2(3 - 2\beta\tan\phi)}{3H^2\sigma_o g}\right\}\right)}$
L		semi-length of specimen (inch)
M_o	=	$\sigma_o H^2/4$
V_o		initial velocity of plate
W		permanent deflections (inch)
W_{max}		maximum permanent deflection (inch)
s		pendulum track
t		duration of response
x,y		Cartesian coordinates defined in Figure 7
β		B/L, aspect ratio
λ	=	$\rho\dfrac{V_o^2 L^2}{M_o}$, non dimensional
ρ		density of specimens lb/in^3
σ_o		yield stress in tension
σ_u		ultimate tensile stress
ϕ		angle between hinge lines ($^\circ$)

INTRODUCTION

Some of the most important elements of the loading of the plates of a ship come from the subjection of the plates to slamming and other dynamic loads. The experimental examination of plates under similar dynamic loading situations could lead to improvements in the selection and use of rectangular plates in ship design.

The majority of theoretical work has been directed towards clamped beams, Symonds and Mentel [1]; cantilever beams, Bodner and Symonds [2]; and circular plates, Jones [3]. Likewise, the experimental work of Humphreys [4]; Florence and Firth [5]; and Jones, et. al. [6], [7] has been completed for several types of beams, plates, and shells under various end conditions. However, there is a noticeable lack of exact solutions for which the directed analysis of experimental work is needed to reinforce the approximations used.

The value of the approximate methods lie in the projection to more realistic shapes. Specifically, in considering fully-clamped rectangular plates, the rigid-plastic analyses may be used if the dynamic energy imparted to the plate is larger than the maximum energy which could be absorbed elastically by the metal. In this manner, the elastic component of strain is ignored. The plates subjected to this dynamic loading are then considered to react in a

perfectly plastic behavior. Secondly, the duration of this dynamic loading must be short in comparison with the natural period of vibration of the plate. In this way, the loading approximates impulsive loading. Lastly, by the comparison of dynamically loaded plates of two materials, mild steel and aluminum 6061-T6, an approximation or justification of the effects of strain-rate sensitivity may be made.

This led to the framework of investigation of the plastic behavior of fully-clamped rectangular plates of mild steel and aluminum 6061-T6 (Jones, et. al., [8]) for one aspect ratio using various plate thicknesses. Quite naturally, the extension of this investigation to plates of various aspect ratios could provide the basis of an experimentally determined spectrum of this plastic behavior from simple beams to square plating. The results of this experimental work should provide guide lines to aid in the development of rigid-plastic behavioral predictions and theory.

EXPERIMENTAL ARRANGEMENT AND DESCRIPTION OF THE EXPERIMENT

The experimental loading and testing of the plate specimens were performed by two methods. The primary method was by the use of the blast table (illustrated in the appendix). This table is constructed of half-inch steel plating mounted upon four steel beam legs. A secondary method utilized the ballistic pendulum in an effort to coordinate the current experimentation with previous work and to substantiate or disprove a close relationship of the explosive calibration data with the free swing results. All work was conducted in the blast test facilities of the MIT Aeroelastic and Structures Research Laboratory.

The plate specimens were cut from one thickness each of aluminum 6061-T6, and hot-rolled mild steel. Twenty specimens of each material were cut of four different aspect ratios. The aspect ratios chosen were .25, .50, .75, and 1.00, the length chosen was 5 inches. The specimen plates were used and tested in the condition in which they were purchased. No surface preparation was needed as in previous tests in which a surface scale had to be removed to provide a uniform plate thickness. Specimen plate size increased with the increasing aspect ratio. In addition, several scrap pieces were cut from each sheet for the cutting of tensile specimens. Care was taken so that these tensile

specimens could be cut against and with the "grain" of the material to show any possible directional or orientational effects on the strength of the plate.

The calculation of the force imparted during each deflection on the table utilizes the calibration of the explosive. This was completed through the use of high speed photography recording the travel of a timepiece after a controlled explosion. Calibration of the explosive yielded an average value of $18.42 \times 10^4 \ \frac{\text{dynes - sec.}}{\text{g. wt. of explosive}}$ from the tests. The multiplication of this parameter by the weight in grams of the explosive yielded the total impulse. Dividing this by the weight in grams of the specimen (the part of the plate not between the clamps), yields the initial velocity in cm/sec (which is then converted to in/sec) imparted to the specimen.

The plates were secured and held by clamps made of .50 inch mild steel approximately one foot square. The specimen hole was cut and machined in the center of each clamp, one set of clamps for each aspect ratio. Twelve holes were drilled at proportional intervals in each of the three larger sets and ten holes were drilled in the smallest set. The extra holes were added at each corner of the specimen plate to compensate for the possible pulling of the plate at the corners. Serrations were then machined on each clamp's face to increase the holding power of the

clamps. Lastly, before conducting any of the tests, all of the clamps were case-hardened and straightened by a professional metallurgical company. This had not been done in previous tests of the rectangular plates and proved a very desirable step by increasing the effectiveness of the serrations of the clamps.

The prepared specimens were placed between the clamps and secured. This unit was secured to a .625 inch mild steel face plate which was bolted to the blast table. High test .375 inch steel bolts were used with washers and nuts and .50 inch steel nuts were used as spacers between the clamps and face plate to avoid any possible compression effects. The bolts and nuts were replaced frequently due to the wear on the threads.

Preparation of the specimens for each test included the initial measurement of the plate thickness by a wide throated micrometer in ten places on each plate. The average thickness of each material was used since the thickness variation was less than .0005 inch over all the specimens. Steel thickness was .106 $\pm$ .0005 inches, aluminum thickness was .1230 $\pm$ .0005 inches. Each specimen was then measured off into a grid of one-half inch squares with a marking pen on each side to use in the deflection measurements after the test.

The explosive used was DuPont DETASHEET D in thicknesses

of .010, .015, and .030 inch. This explosive, officially designated Dupont EL506D is 63 percent PETN, 8 percent nitrocellulose, and the rest a plasticizer. On each specimen, a .250 inch sheet of polyurethane was initially glued, cut to the size of the specimen to protect against spalling. The explosive was then glued to the foam with a small portion of the edge of the explosive taped with masking tape. This was to prevent the jerking of the explosive sheet off of the specimen due to the force of the impulse.

Additional thicknesses of the explosive were made by laying sheet upon sheet. For example, a .020 inch thick sheet was made from two .010 inch thick sheets. "Thinner" sheets were made by symmetrically cutting small rectangles from the entire sheet to maintain a uniform load distribution. Each sheet of explosive was carefully weighed before use.

Previous experimental work had proven that an adequate detonation was provided by a single leader attached at the middle of the specimen on the centerlines. A second choice using a three fingered lead had proven that this arrangement did not eliminate the possibilities of non-symmetrical deflections. The leads were thin strips of .010 inch explosive about one foot long, cut to a point, and glued to the explosive. The lead was stretched tightly back to a lead

block arrangement holding the Dupont #6 electric blasting cap which detonated the charge. This apparatus prevented the chance of an effect from the blasting cap, and minimized any possible leader effects. Several plates were tested using a leader without explosive to verify that lead effects were small. In each of these tests, no permanent deflections occurred.

The secondary method utilized the ballistic pendulum. This pendulum is illustrated in the appendix. It had been constructed for earlier experiments conducted involving beams and plates but as such had to be modified to accommodate to these experiments.

The pendulum was made from a two foot steel I-beam with a welded face plate to which the clamps could be attached. The face plate was drilled for the one quarter aspect ratio clamps which were used in the table type method. Because these clamps were heavier than the ones used previously, extra ballast had to be used to balance the pendulum. The extra weight amounted to approximately thirty pounds. The wire mounting arrangement which suspended the pendulum in four places from tracks in the ceiling were modified by the use of turnbuckles. These also aided in the balancing of the pendulum. All four wires were at a right angle along the longitudinal direction of the pendulum.

However, the after pair of suspension wires were extended out horizontally from the tracks so that the wires would cant in, forming an angle with the lateral dimension of the pendulum in an effort to stabilize the swing. As this had not been done previously, several tests were done to determine any additional damping that may have contributed significantly to the swing of the pendulum.

Determining this frictional loss was done by allowing the pendulum to swing through a number of cycles and then measuring the total loss of the pendulum over each swing. In this way, the total pendulum loss over the swing could be divided by the number of swings to calculate the average loss. For all of the tests, the average loss was less than one percent over the half-swing of the pendulum. These swings were recorded on heat sensitive paper that was used during the experiment.

The heat sensitive paper was taped to a curved steel track which laid under the pendulum. A heat sensitive needle was made from a two inch loop of steel wire which was connected to two 1 1/2 volt dry cell batteries. The wire was zeroed before each test as the pendulum was balanced. Care was taken so that the needle did not drag along the track to avcid friction. This may have jeopardized a continuous track which a small degree of contact

would have insured.

The securing of the clamps to the pendulum utilized high test .375 inch steel bolts and nuts with the .50 inch spacer nuts to keep the specimen plate from direct contact with the face plate of the pendulum. Specimens were prepared identically with the table preparation and the leads were glued to the explosive. Then the lead was tightly stretched to the lead blocks on the floor which held the #6 electric blasting cap. A .50 inch steel shield was used to contain the force of this blasting cap.

To maximize the credibility of the relatively few tests conducted using the pendulum, a great deal of care was taken with each test. Before each shot, the pendulum was carefully balanced and all of the suspension hooks were tightened. On the average, each pendulum shot required six times the amount of time and effort of each table test.

DISCUSSION OF RESULTS

The appendix contains a summary of results for each of the forty specimens. Each specimen was measured around the edges at one-half inch intervals over the half-inch square grid described previously. They were measured by a dial gauge to the .0001 inch on a plane surface. However, they had been elastically unloaded when they were taken from the clamps. Thus, the results are measurements of the permanent plastic deflections. There is a plot of the maximum deflection of each plate versus the explosive parameters V_o and λ for each aspect ratio. These plots clearly show an almost linear relationship of the W_{max}/H with the V_o in/sec. In each aspect ratio, slopes of the lines of W_{max}/H versus V_o in/sec for the aluminum and the mild steel were remarkably close. These slopes increased with the increasing aspect ratio. The plots of W_{max}/H versus λ show the effects of the strain-rate sensitivity of the mild steel and the correlation of aluminum response to a Tresca solution.

There is also a plot of the gauge apparatus measurements against micrometer measurements of various thickness. However, slight plate curvature sometimes made the readings difficult. There were fifty-five measurements recorded for each .250 aspect ratio specimen, seventy-seven for each .500 ratio, ninety-nine for each .750, and one hundred and

twenty-one for the 1.0 aspect ratio specimens. Only the maximum deflections of each plate were plotted, although they were not all in the geometrical center of each specimen. The appendix contains a sample profile plot of one type of plate for each aspect ratio to show a characteristic deflection profile.

A few of the specimens exhibited serious shear with separation and translation along one or more of the edges and are noted as such. However, the majority of the specimens did not show this effect. The clear imprint of the serrated edges of the clamp on the specimen plates show that there was very little slip of the plates.

To compare the performance of the pendulum with the table method, a graph is plotted of the non-dimensional ratio (max deflection/thickness) versus the V_o in in/sec. as computed first from the track of the pendulum using the equation:

$$V_o = \frac{\sqrt{\{2g(WD^2 + W_s L_s^2)D(1 - \cos\theta_m)W\}}}{W_s L_s}$$

which is developed and defined in the appendix; and secondly, by the calibration data method described earlier. The plot is of the .250 aspect ratio for the steel plates, of which there were five fairly good tracks.

The results agree with the observed performance of the pendulum. Considering the effort and results of the cali-

bration parameter determination, the curve using that parameter is considered the baseline. The smallest pendulum V_o in/sec is higher than the smallest parameter V_o in/sec. Conversely, the largest pendulum V_o in/sec is lower than the largest parameter V_o in/sec, with a fairly good agreement over the middle range of values of V_o. This indicates a type of "jump" response, the pendulum will overreact to a relatively small impulse and underreact, due to large forces, small time periods and possible "jump damping," to larger impulses. These jumps may not be attributed to random lead effects since a blank shot using only the lead produced no pendulum response. Part of this reaction may be attributed to a small moment produced by the difference of the distance from the center of gravity of the pendulum to the pendulum suspension point, and the distance from the center of gravity of the plate to the pendulum suspension point. In these experiments, this difference was .40 inch, similar to the magnitude of earlier work conducted with this pendulum. Over the entire distance from the center of pendulum activity to the suspension point, this is .321 percent. This response would probably be characteristic of one hundred tests had they been completed with the pendulum.

CONCLUSIONS

The results of the experimental dynamic loading of mild steel (a strain-rate sensitive material) and aluminum 6061-T6 (a strain-rate insensitive material) for the 40 tests conducted of four aspect ratios are illustrated by graphical and tabular results in the appendix of this text. They are compared with the results of previous experimental work and the predictions of a Tresca solution [9] for fully-clamped rectangular plates subjected to dynamic loading.

From the analysis of the permanent plate profiles after dynamic loading a similarity to previous predicted and experimental values justifies the approximate prediction of work done by Wood [10] , using uniformly distributed static loading, and Jones [8]. The off-center maximum deflection which occurred in some cases are obviously not predicted by theory while they are clearly a physical reality, probably resulting from non-homogeneous properties of the metals. Random leader effects and non-uniform explosions are believed to be secondary to the non-homogeneous properties of the metals.

The experimental results indicate that a linear relationship of maximum deflection versus imparted energy over the region of plastic behavior until dynamic failure,

through complete shear and total separation of the plate, is a good approximation. The maximum deflection increases with increasing aspect ratio for a given λ as indicated by the increasing slopes of the graphs.

The comparisons of the maximum deflection with the non-dimensional parameter λ indicates that there is a larger deflection for aluminum than for steel. This illustrates the dependence of mild steel on strain-rate sensitivity while aluminum 6061-T6 does not demonstrate this property and conforms relatively with the prediction of a Tresca yield solution for a perfectly plastic material. Thus, a correlation of the results of mild steel plates must account for an increasing yield stress that will occur at high strain rates. Such a correction for beams indicates that the lower yield stress is a factor of the plastic strain rate, the static yield stress, and material constants [11]. Lastly, the comparison of maximum deflection with the parameter $\beta\lambda$ where β is the aspect ratio provides a valuable justification of the accuracy of the results for each material.

In considering the experimental procedure, the problems and inaccuracies of the pendulum method should be balanced by the relative inexpensiveness of the method in comparison to the table-calibration method. If resources are available to conduct an adequate explosive calibration

procedure, this method should probably be used. The calibration parameter should not be assumed to have a large degree of sanctity. Clearly, additional work in determining this parameter would enhance its worth. At best, the calibration parameter is an average value of the explosive force. Thus, in some explosions, the force imparted by the explosive may be more or less than the parameter would indicate. Here the value of a direct measure of V_o through a pendulum track could justify its use. However, the basic pendulum response should limit its use to any great degree in the future for work of this type.

The development of a method for measuring the deflections while the specimens are still clamped will also eliminate the need of correcting the results in order to account for the elastic unloading of the plates, when they are separated from the clamps.

A desirable examination of the work of this type with current plate selection and uses, could lead to new concepts of plate shape selection. In regards to ship construction, these selections would need a study of the differences in cost and construction due to additional frames, stiffners, and plate shaping procedures, as in an input. Information supplied to a computer could swiftly and easily provide an

optimum solution through the coordination of economics, feasibility, and plate strength.

RECOMMENDATIONS

The effects of different aspect ratios upon the plastic behavior of plates under dynamic loading are illustrated in this work. Previous work has given the effects of thickness. A logical extension of this work would lead to experimental work varying the thickness and the aspect ratio. From this, an inclusive grid could be established determined by the results and presented with the framework of theoretical calculations. Entering the figures and charts with a given aspect ratio and thickness could lead to an accurate prediction of plastic behavior under dynamic loading. Such a projection is illustrated in Figure 1.

Procedures have now been established for the calibration of explosives used, the clamping and securing of plates during testing, and the illustration of the results. A great deal of equipment has been made and could be used or modified to accommodate this additional work under qualified supervision. Such a program would greatly enhance the development of theoretical and experimental comparisons while benefiting from the foundation of previous work.

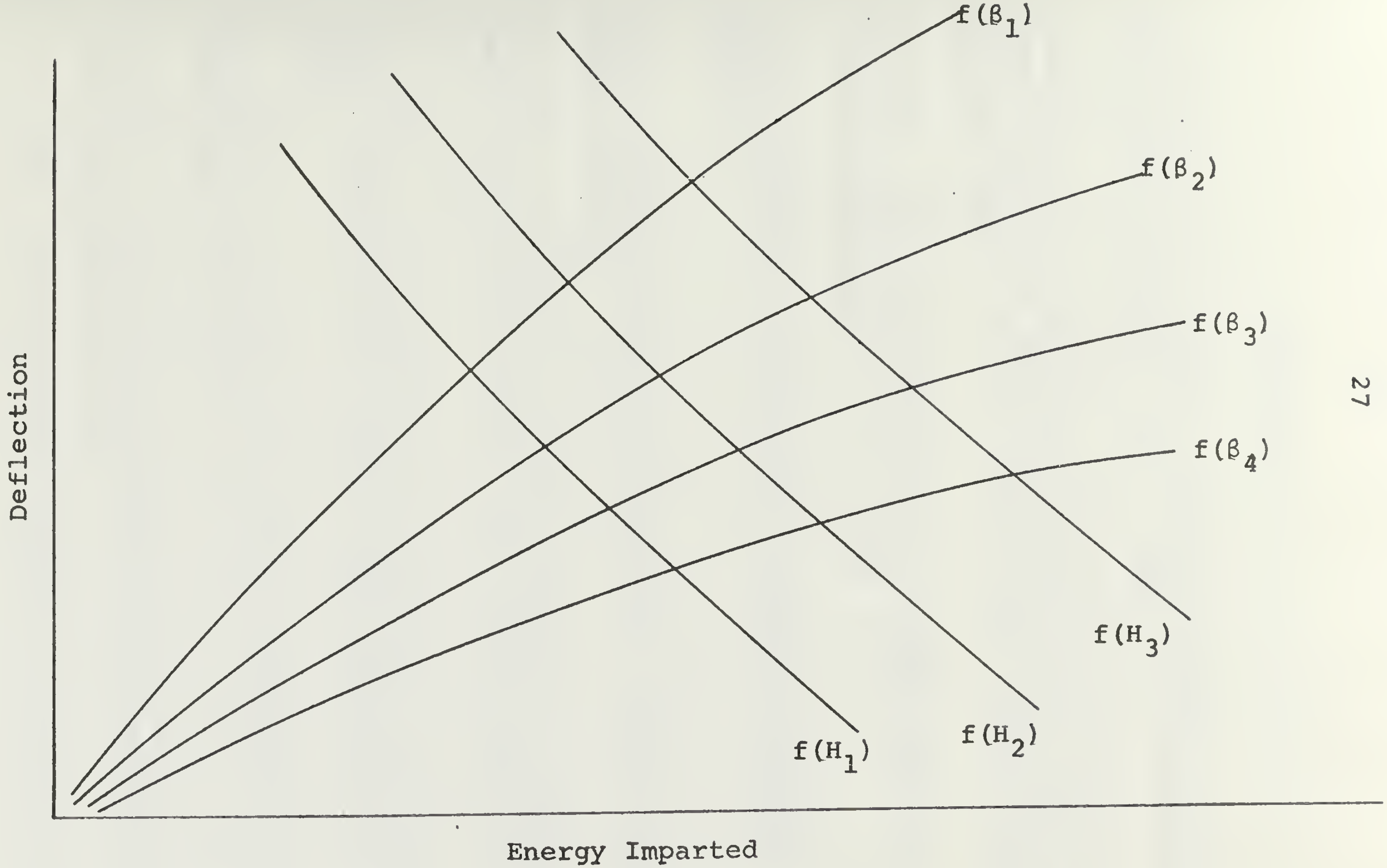

Figure 1

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APPENDIX A

The following figures illustrate the apparatus of the experimental work.

Figure 2 A side view of the blast table with specimen plate secured and ready for a test. The diagram is drawn to relative scale.

Figure 3 A side view of the ballastic pendulum with specimen plate secured and ready for a test. The diagram is drawn to relative scale.

Figure 4 A diagram of a clamp, illustrating the clamp face, machined specimen hole, and face serrations. This clamp was used for the 1.0 aspect ratio, consequently, clamps used for smaller aspect ratios have holes at proportionate intervals. This figure is drawn at side .375 in = 1 inch.

Figure 5 This is a pictorial perspective of a typical plate after it has been dynamically loaded. The hinge lines are emphasized and the region of maximum deflection lies in the center of the specimen.

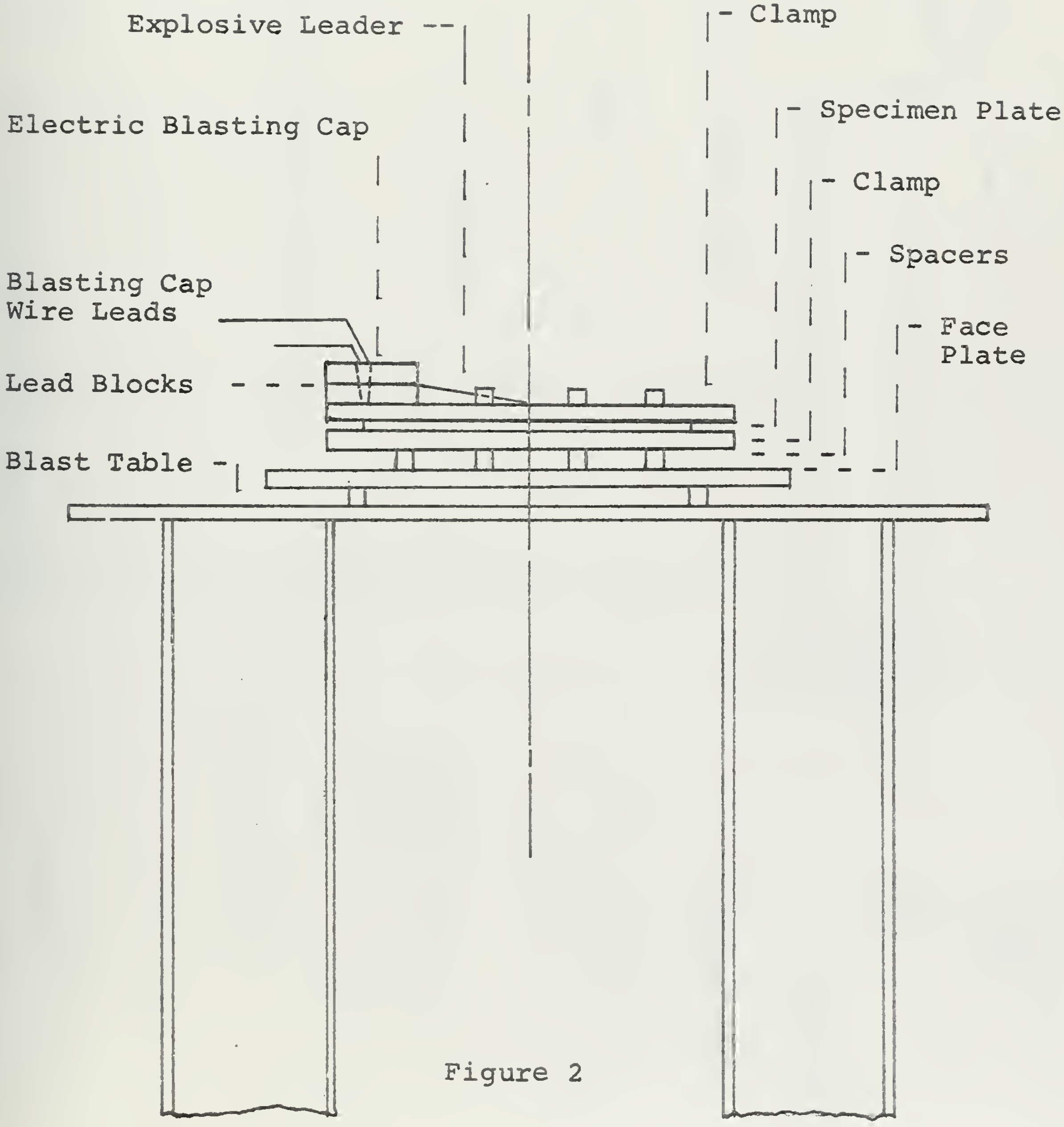
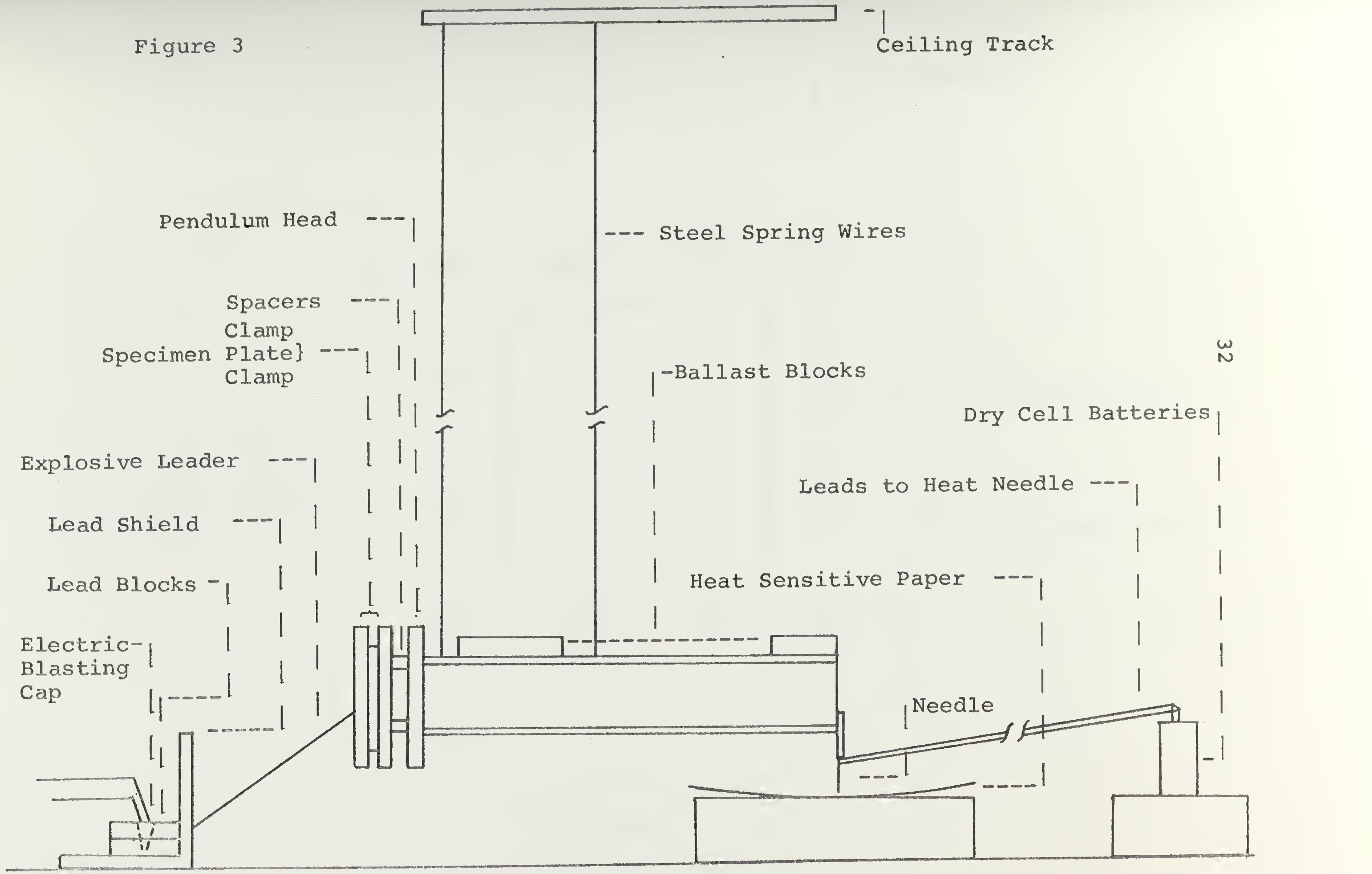

Explosive Leader
Clamp
Electric Blasting Cap
Specimen Plate
Clamp
Spacers
Blasting Cap
Wire Leads
Face
Plate
Lead Blocks
Blast Table

Figure 2

Figure 3


Ceiling Track
Pendulum Head
Steel Spring Wires
Spacers
Clamp
Specimen Plate
Clamp
Ballast Blocks
Dry Cell Batteries
Explosive Leader
Leads to Heat Needle
Lead Shield
Lead Blocks
Heat Sensitive Paper
Electric-
Blasting
Cap
Needle

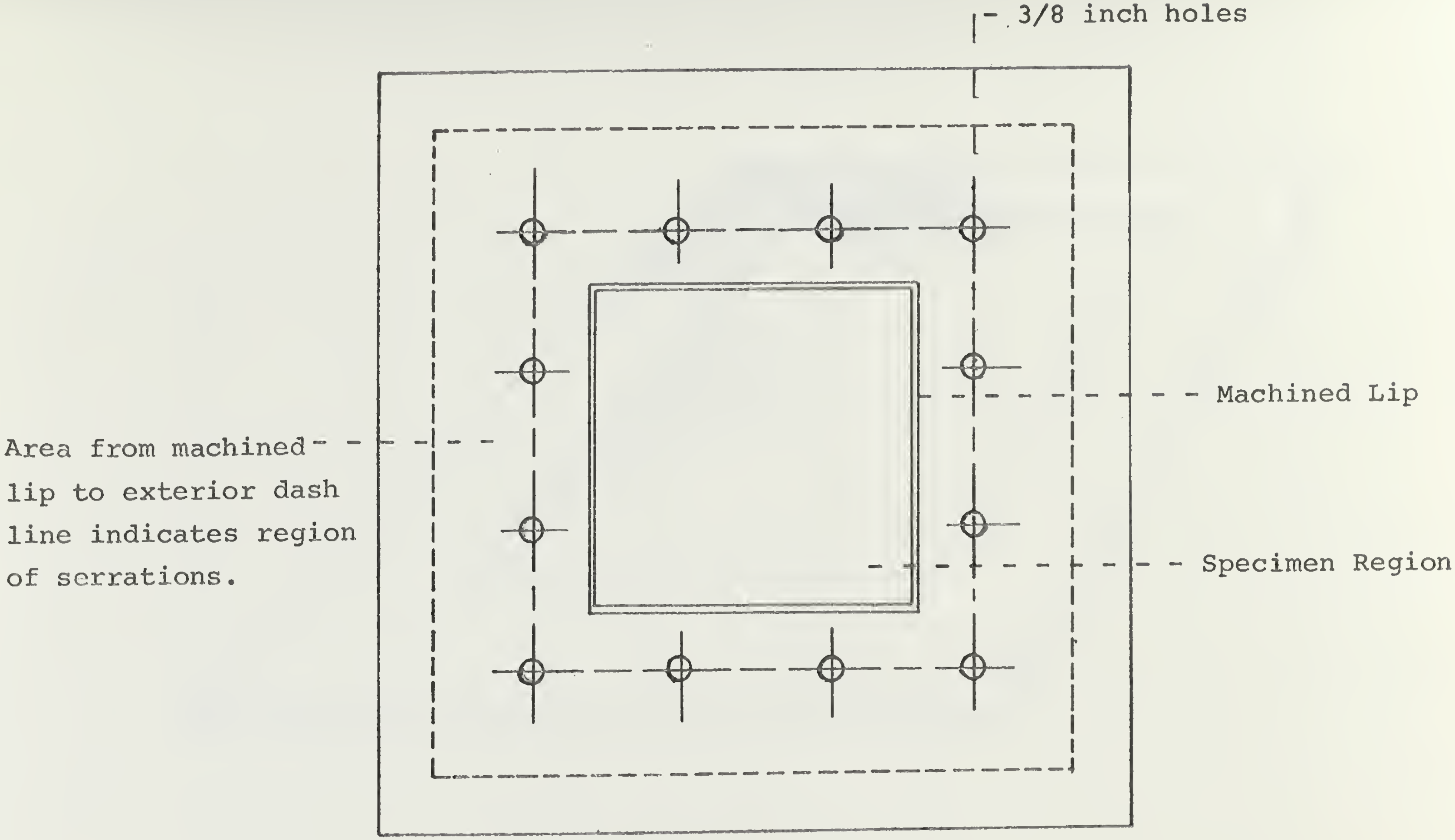

3/8 inch holes
Machined Lip
Specimen Region
Area from machined lip to exterior dash line indicates region of serrations.

Figure 4

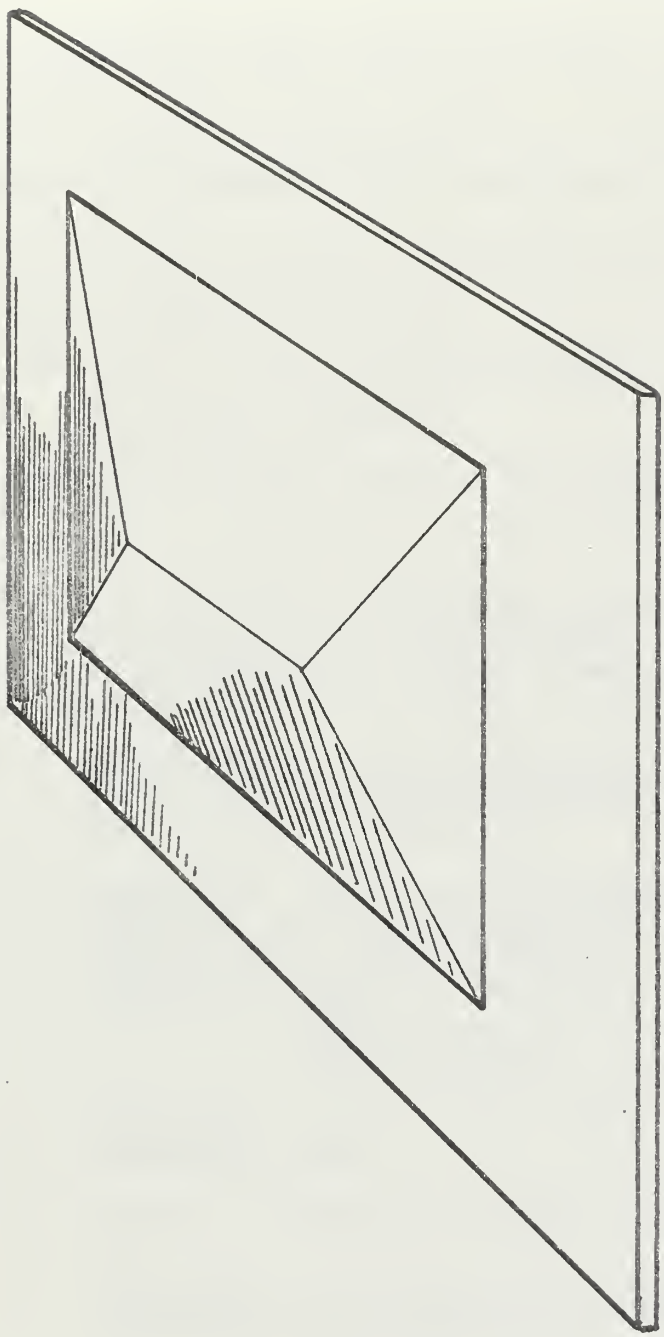


Figure 5
A Deflected Specimen

APPENDIX B

Specimen deflections were measured by the use of a dial gauge mounted above a plane surface. A justification of the accuracy of this method is illustrated by the plot of gauge readings taken with this apparatus versus micrometer readings of calibrated samples.

Figure 6 Plot of Gauge Readings versus Micrometer Readings.

The specimen plates were laid out in a grid and deflections measured.

Figure 7 Illustration of a sample specimen plate (β = .750) showing x,y coordinates, hinge lines, and angle ϕ.

Table 1 These are the tabular results of the deflection measurements. The table is labeled as:

<u>Specimen</u>: This shows the exact specimen in terms of material, aspect ratio, and a number.
Example: Steel - .25 - #1
Steel, β = .25,
Plate number 1

<u>Thickness</u>: This is the plate thickness used.

<u>Method</u>: Pendulum or Table method.

<u>Explosive</u>: The thickness and weight in grams of the explosive used. (DuPont DETASHEET D).

<u>Weight</u>: The weight in grams of the entire plate. (Only the part of the specimen plate not within the clamps is considered the target.)

Reference Value: This value is an equivalent plate thickness in inches after the dynamic loading and reflects plate curvature due to unloading.

Max. Gage Deflection: Max. deflection in inches of the specimen plate.

Observed Angle: This is the observed ϕ between the hinge lines. Non-descript indicates that the plate deflection was too small to clearly produce an angle between the hinge lines.

Max. Deflection: This is the maximum deflection in inches equal to the maximum gage deflection minus the reference value.

The readings in x,y, are the gage deflections in inches at each point x,y. True deflections may be obtained by subtracting the reference value from the gage reading.

Figures 8-15 These figures are side profile views of true deflection readings for each of the plates labeled at the top of the figure. The plotted lines represent deflection along each longitudinal centerline and along each longitudinal line from the centerline to the edge line.

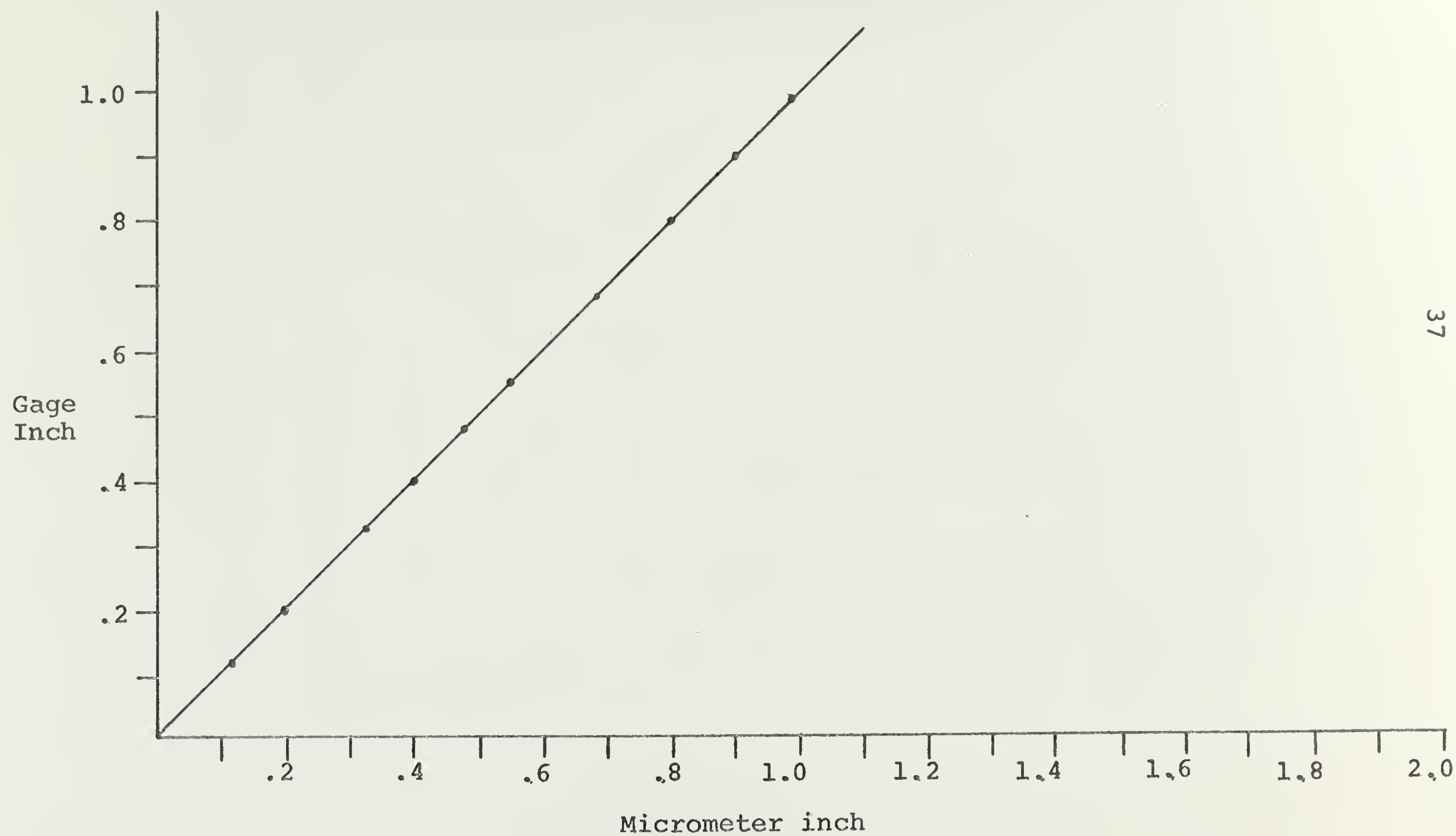


Figure 6

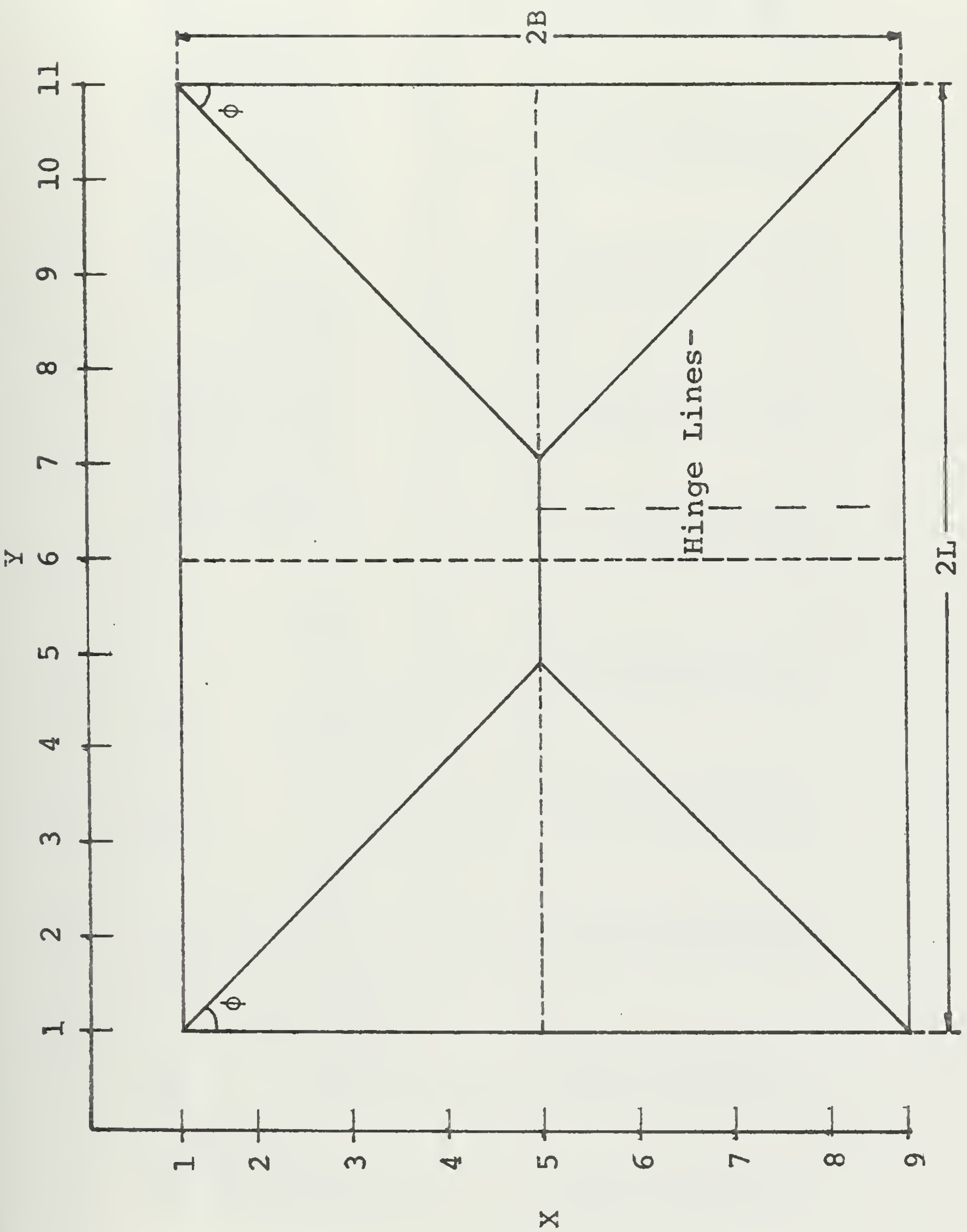


Figure 7

SPECIMEN: Steel - .25 - #1

METHOD: Pendulum

WEIGHT: 958.4 g.

MAX. GAGE DEFLECTION: .1673 inch

MAX. DEFLECTION: .0320 inch

THICKNESS: .1060 ± .0005 inch

EXPLOSIVE: .010 in. - 1.500 g.

REFERENCE VALUE: .1353 inch

OBSERVED ANGLE: Non-descript

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1313	.1315	.1331	.1342	.1451	.1324	.1320	.1373	.1383	.1403	.1390
2	.1371	.1397	.1432	.1432	.1433	.1468	.1471	.1441	.1436	.1442	.1411
3	.1397	.1498	.1620	.1661	.1673	.1664	.1619	.1615	.1586	.1534	.1434
4	.1397	.1467	.1519	.1530	.1531	.1536	.1541	.1544	.1542	.1504	.1433
5	.1396	.1425	.1545	.1457	.1477	.1478	.1489	.1501	.1494	.1462	.1420

Table 1

SPECIMEN: Steel - .25 - #2
METHOD: Pendulum
WEIGHT: 953.8 g.
MAX. GAGE DEFLECTION: .2030 inch
MAX. DEFLECTION: .0683 inch

THICKNESS: .1060 $\pm$ .0005 inch
EXPLOSIVE: .015 in. - 2.400 g.
REFERENCE VALUE: .1347 inch
OBSERVED ANGLE: Non-descript

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1408	.1444	.1471	.1470	.1470	.1503	.1508	.1513	.1509	.1537	.1510
2	.1485	.1686	.1642	.1621	.1649	.1645	.1659	.1639	.1630	.1627	.1535
3	.1528	.1790	.1967	.2013	.2030	.2012	.1991	.1995	.1971	.1842	.1585
4	.1510	.1641	.1698	.1706	.1715	.1692	.1722	.1702	.1689	.1664	.1552
5	.1497	.1563	.1581	.1569	.1593	.1571	.1601	.1607	.1595	.1590	.1543

Table 1

SPECIMEN: Steel - .25 - #3
METHOD: Pendulum
WEIGHT: 957.3 g.
MAX. GAGE DEFLECTION: .2115 inch
MAX. DEFLECTION: .0779 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .020 in. - 3.10 g.
REFERENCE VALUE: .1336 inch
OBSERVED ANGLE: 56°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1284	.1294	.1345	.1346	.1305	.1299	.1290	.1316	.1319	.1301	.1299
2	.1329	.1547	.1504	.1508	.1501	.1481	.1508	.1507	.1515	.1467	.1338
3	.1399	.1915	.2106	.2115	.2086	.2046	.2034	.2062	.2096	.1931	.1457
4	.1385	.1674	.1699	.1674	.1647	.1767	.1675	.1703	.1751	.1660	.1412
5	.1364	.1466	.1451	.1435	.1422	.1435	.1437	.1495	.1504	.1579	.1386

Slight shear, off-center deflection.

Table 1

SPECIMEN: Steel - .25 - #4

METHOD: Pendulum

WEIGHT: 960.5 g.

MAX. GAGE DEFLECTION: .3351 inch

MAX. DEFLECTION: .1997 inch

THICKNESS: .1060 ± .0005 inch

EXPLOSIVE: .035 in. - 5.470 g.

REFERENCE VALUE: .1354 inch

OBSERVED ANGLE: 54°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1350	.1391	.1267	.1465	.1506	.1569	.1506	.1511	.1471	.1390	.1334
2	.1494	.2025	.2187	.2161	.2231	.2124	.2112	.2133	.2141	.1785	.1395
3	.1331	.3131	.3272	.3239	.3192	.3180	.3240	.3330	.3351	.3061	.1440
4	.1532	.2076	.2201	.2116	.2222	.2306	.2260	.2240	.2311	.1968	.1470
5	.1366	.1569	.1549	.1590	.1471	.1692	.1544	.1661	.1721	.1665	.1410

Large shear along one edge, off-center deflection.

Table 1

SPECIMEN: Steel - .25 - #5
METHOD: Pendulum
WEIGHT: 958.8 g.
MAX. GAGE DEFLECTION: .2620 inch
MAX. DEFLECTION: .1260 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .025 in. - 3.605 g.
REFERENCE VALUE: .1360 inch
OBSERVED ANGLE: 56°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1171	.1200	.1258	.1240	.1240	.1237	.1278	.1234	.1244	.1254	.1238
2	.1210	.1414	.1544	.1582	.1631	.1641	.1639	.1725	.1776	.1724	.1404
3	.1254	.1909	.2154	.2202	.2254	.2299	.2372	.2484	.2620	.2429	.1354
4	.1263	.1489	.1531	.1540	.1544	.1556	.1614	.1686	.1654	.1639	.1368
5	.1244	.1306	.1349	.1319	.1325	.1329	.1339	.1489	.1409	.1372	.1255

Slight shear, off-center deflection.

Table 1

SPECIMEN: Aluminum - .25 - #1
METHOD: Pendulum
WEIGHT: 328.0 g.
MAX. GAGE DEFLECTION: .2103 inch
MAX. DEFLECTION: .0608 inch

THICKNESS: .1230 ± .0005 inch
EXPLOSIVE: .010 in. - 1.510 g.
REFERENCE VALUE: .1495 inch
OBSERVED ANGLE: Non-descript

Y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1602	.1605	.1595	.1679	.1568	.1561	.1524	.1522	.1499	.1441	.1399
2	.1605	.1699	.1639	.1588	.1593	.1592	.1604	.1539	.1678	.1576	.1419
3	.1646	.1874	.1736	.1644	.1639	.1694	.1761	.1952	.2103	.1930	.1469
4	.1552	.1629	.1564	.1504	.1509	.1525	.1562	.1698	.1645	.1585	.1448
5	.1554	.1563	.1493	.1463	.1463	.1461	.1441	.1423	.1473	.1414	.1394

Off-center deflection

Table 1

SPECIMEN: Aluminum - .25 - #2

METHOD: Table

WEIGHT: 378.0 g.

MAX. GAGE DEFLECTION: .3142 inch

MAX. DEFLECTION: .1634 inch

THICKNESS: .1230 ± .0005 inch

EXPLOSIVE: .015 in. - 2.355 g.

REFERENCE VALUE: .1508 inch

OBSERVED ANGLE: 56°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1479	.1533	.1543	.1543	.1542	.1553	.1542	.1522	.1522	.1522	.1468
2	.1537	.1802	.2003	.2013	.1963	.1998	.1883	.1948	.1998	.1921	.1508
3	.1579	.2389	.2786	.2884	.2908	.2906	.3056	.3142	.3076	.2853	.1580
4	.1720	.1798	.1916	.1887	.1850	.1902	.2042	.2090	.2080	.1972	.1499
5	.1494	.1689	.1555	.1629	.1613	.1623	.1623	.1619	.1603	.1688	.1437

Off-center deflection

Table 1

SPECIMEN: Aluminum - .25 - #3
METHOD: Table
WEIGHT: 378.0 g.
MAX. GAGE DEFLECTION: .3459 inch
MAX. DEFLECTION: .2005 inch

THICKNESS: .1230 ± .0005 inch
EXPLOSIVE: .020 in. - 3.035 g.
REFERENCE VALUE: .1454 inch
OBSERVED ANGLE: 54°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1430	.1529	.1499	.1459	.1499	.1451	.1465	.1504	.1504	.1489	.1399
2	.1558	.2059	.2177	.2124	.2021	.1934	.1986	.2185	.2246	.1938	.1438
3	.1539	.3264	.3411	.3224	.3054	.3004	.3169	.3341	.3459	.2924	.1494
4	.1456	.2061	.2158	.2079	.2054	.2053	.2114	.2104	.2262	.1889	.1373
5	.1359	.1484	.1494	.1464	.1474	.1534	.1464	.1542	.1704	.1514	.1376

Off-center deflection

Table 1

SPECIMEN: Aluminum - .25 - #4

METHOD: Table

WEIGHT: 377.8 g.

MAX. GAGE DEFLECTION:

MAX. DEFLECTION:

THICKNESS: .1230 $\pm$ .0005 inch

EXPLOSIVE: .025 in. - 3.825 g.

REFERENCE VALUE:

OBSERVED ANGLE:

y \ x	1	2	3	4	5	6	7	8	9	10	11
1											
2											
3											
4											
5											

Completely sheared, total separation.

Table 1

SPECIMEN: Aluminum - .25 - #5

METHOD: Table

WEIGHT: 379.5 g.

MAX. GAGE DEFLECTION: .3440 inch

MAX. DEFLECTION: .1464 inch

THICKNESS: .1230 ± .0005 inch

EXPLOSIVE: .015 in. - 2.165 g.

REFERENCE VALUE: .1976 inch

OBSERVED ANGLE: 56°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1795	.2010	.2014	.1941	.1989	.1904	.1964	.1875	.1864	.1946	.1858
2	.1951	.2480	.2621	.2569	.2569	.2599	.2527	.2351	.2311	.2198	.1898
3	.1934	.3198	.3440	.3440	.3372	.3324	.3243	.3129	.3148	.2732	.1859
4	.1813	.2114	.2238	.2314	.2284	.2236	.2243	.2312	.2215	.1956	.1840
5	.1783	.1919	.1989	.1894	.1859	.1914	.1859	.1864	.1884	.1838	.1847

Off-center deflection

Table 1

SPECIMEN: Steel - .50 - #1	THICKNESS: .1060 ± .0005 inch
METHOD: Table	EXPLOSIVE: .010 in. - 3.28 g.
WEIGHT: 944.0 g.	REFERENCE VALUE: .1536 inch
MAX. GAGE DEFLECTION: .2364 inch	OBSERVED ANGLE: Non-descript
MAX. DEFLECTION: .0828 inch	

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1487	.1571	.1600	.1604	.1662	.1709	.1685	.1710	.1687	.1654	.1594
2	.1516	.1636	.1714	.1754	.1794	.1838	.1834	.1819	.1779	.1714	.1612
3	.1560	.1592	.1978	.2016	.2087	.2152	.2155	.2108	.2004	.1868	.1680
4	.1567	.1890	.2054	.2198	.2205	.2364	.2352	.2205	.2190	.1965	.1685
5	.1554	.1744	.1910	.1985	.2120	.2101	.2120	.2104	.2020	.1880	.1630
6	.1500	.1570	.1518	.1701	.1698	.1694	.1690	.1669	.1630	.1612	.1520
7	.1455	.1540	.1541	.1526	.1510	.1514	.1519	.1518	.1509	.1509	.1467

Table 1

SPECIMEN: Steel - .50 - #2

METHOD: Table

WEIGHT: 949.5 g.

MAX. GAGE DEFLECTION: .3103 inch

MAX. DEFLECTION: .1799 inch

THICKNESS: .1060 ± .0005 inch

EXPLOSIVE: .015 in. - 4.515 g.

REFERENCE VALUE: .1304 inch

OBSERVED ANGLE: 53°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1271	.1309	.1314	.1341	.1400	.1341	.1391	.1338	.1372	.1351	.1282
2	.1292	.1446	.1628	.1770	.1944	.2075	.2011	.1946	.1865	.1696	.1363
3	.1311	.1953	.2169	.2491	.2602	.2716	.2885	.2737	.2608	.2209	.1411
4	.1279	.1885	.2370	.2772	.2944	.3053	.3103	.3086	.2859	.2254	.1401
5	.1277	.1299	.2101	.2395	.2580	.2668	.2787	.2762	.2502	.2097	.1378
6	.1286	.1441	.1658	.1609	.1869	.1956	.1992	.1877	.1855	.1669	.1322
7	.1266	.1292	.1336	.1380	.1400	.1395	.1415	.1379	.1393	.1338	.1269

Table 1

SPECIMEN: Steel - .50 - #3

METHOD: Table

WEIGHT: .1070 g.

MAX. GAGE DEFLECTION: .3454 inch

MAX. DEFLECTION: .2175 inch

THICKNESS: .1060 ± .0005 inch

EXPLOSIVE: .020 in. - 5.91 g.

REFERENCE VALUE: .1279 inch

OBSERVED ANGLE: 51°

Y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1360	.1408	.1467	.1489	.1550	.1618	.1604	.1562	.1524	.1498	.1452
2	.1376	.1607	.1829	.1958	.2023	.2041	.2049	.2026	.1949	.1699	.1481
3	.1388	.2233	.2711	.2846	.2909	.2927	.2941	.2860	.2694	.2265	.1514
4	.1414	.2431	.3152	.3244	.3418	.3454	.3424	.3326	.3142	.2422	.1514
5	.1394	.2245	.2820	.2997	.3087	.3105	.3034	.2977	.2841	.2183	.1508
6	.1388	.1773	.2108	.2184	.2220	.2302	.2260	.2175	.2129	.1785	.1483
7	.1364	.1485	.1585	.1635	.1675	.1641	.1675	.1649	.1567	.1486	.1440

Table 1

SPECIMEN: Steel - .50 - #4
METHOD: Table
WEIGHT: 1062.0 g.
MAX. GAGE DEFLECTION: .5472 inch
MAX. DEFLECTION: .4192 inch

THICKNESS: .1060 $\pm$ .0005 inch
EXPLOSIVE: .030 in. - 9.01 g.
REFERENCE VALUE: .1280 inch
OBSERVED ANGLE: 51°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1459	.1527	.1773	.1817	.1896	.2013	.1932	.1902	.1844	.1689	.1546
2	.1635	.2235	.2647	.2767	.2897	.2910	.2900	.2745	.2721	.2393	.1595
3	.1652	.3177	.4065	.4962	.5603	.5637	.5622	.5575	.4266	.3454	.1690
4	.1692	.3378	.4687	.5242	.5360	.5422	.5472	.5451	.5995	.3671	.1709
5	.1633	.3170	.4072	.4497	.4686	.4673	.4658	.4588	.4312	.3497	.1612
6	.1582	.2461	.2806	.2859	.3040	.3093	.3034	.2899	.2941	.2499	.1678
7	.1492	.1662	.1754	.1893	.1912	.1952	.1861	.1682	.1608	.1572	.1526

Slight shear

Table 1

SPECIMEN: Steel - .50 - #5
METHOD: Table
WEIGHT: 1062.0 g.
MAX. GAGE DEFLECTION: .9737 inch
MAX. DEFLECTION: .8451 inch

THICKNESS: .1060 $\pm$ .0005 inch
EXPLOSIVE: .045 in. - 14.172 g.
REFERENCE VALUE: .1286 inch
OBSERVED ANGLE: 52°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1403	.1551									.1515
2	.1495	.2616	.3846	.4662	.5298	.5357	.5180	.4710	.4486	.3202	
3	.1686	.4313	.6479	.7505	.8431	.8661	.8351	.7873	.6934	.4065	
4	.1706	.4853	.7317	.8786	.9453	.9737	.8628	.8008	.7686	.5226	
5	.1606	.4053	.6143	.6897	.7641	.7884	.7601	.7131	.6024	.5707	
6	.1450	.2673	.3478	.4393	.4855	.5598	.4970	.4408	.3811	.2851	
7	.1526										.1486

Large shear, separation and translation.

Table 1

SPECIMEN: Aluminum - .50 - #1
METHOD: Table
WEIGHT: 378.0 g.
MAX. GAGE DEFLECTION:
MAX. DEFLECTION:

THICKNESS: .1230 $\pm$ .0005 inch
EXPLOSIVE: .010 in. - 9.280 g.
REFERENCE VALUE:
OBSERVED ANGLE:

y \ x	1	2	3	4	5	6	7	8	9	10	11
1											
2											
3											
4											
5											
6											
7											

Completely sheared, total separation.

Table 1

SPECIMEN: Aluminum - .50 - #2
METHOD: Table
WEIGHT: 379.5 g.
MAX. GAGE DEFLECTION: .2908 inch
MAX. DEFLECTION: .1423 inch

THICKNESS: .1230 $\pm$ .0005 inch
EXPLOSIVE: .010 in. - 3.045 g.
REFERENCE VALUE: .1485 inch
OBSERVED ANGLE: 52°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1579	.1622	.1663	.1697	.1728	.1742	.1726	.1744	.1738	.1708	.1662
2	.1591	.1636	.1694	.1751	.1829	.1916	.1970	.2062	.2079	.2000	.1699
3	.1615	.1686	.1755	.1872	.2042	.2305	.2512	.2642	.2641	.2389	.1734
4	.1650	.1728	.1814	.1967	.2179	.2456	.2709	.2908	.2846	.2494	.1644
5	.1665	.1731	.1810	.1944	.2108	.2306	.2543	.2561	.2578	.2398	.1735
6	.1655	.1715	.1790	.1858	.1950	.2008	.2142	.2155	.2132	.2050	.1728
7	.1651	.1700	.1755	.1805	.1815	.1817	.1803	.1802	.1803	.1778	.1728

Off-center deflection

Table 1

SPECIMEN: Aluminum - .50 - #3 THICKNESS: .1230 ± .0005 inch

METHOD: Table EXPLOSIVE: .015 in. - 4.860 g.

WEIGHT: 380.0 g. REFERENCE VALUE: .1722 inch

MAX. GAGE DEFLECTION: .5604 inch OBSERVED ANGLE: 51°

MAX. DEFLECTION: .3882 inch

Y \ X	1	2	3	4	5	6	7	8	9	10	11
1	.1673	.1683	.1763	.1807	.1803	.1810	.1783	.1761	.1763	.1683	.1583
2	.1714	.2130	.2569	.2794	.2886	.2935	.2840	.2802	.2882	.2578	.1728
3	.1742	.2940	.3945	.4265	.4479	.4573	.4548	.4523	.4475	.3523	.1787
4	.1754	.3045	.4523	.5082	.5230	.5282	.5423	.5604	.5189	.3800	.1925
5	.1723	.2777	.3855	.4233	.4331	.4495	.4559	.4593	.4311	.3482	.1745
6	.1655	.2078	.2585	.2743	.2748	.2772	.2753	.2762	.2758	.2427	.1687
7	.1639	.1733	.1803	.1772	.1871	.1973	.1903	.1900	.1894	.1793	.1653

Slight shear

Table 1

SPECIMEN: Aluminum - .50 - #4

METHOD: Table

WEIGHT: 380.0 g.

MAX. GAGE DEFLECTION: .6942 inch

MAX. DEFLECTION: .5442 inch

THICKNESS: .1230 $\pm$ .0005 inch

EXPLOSIVE: .020 in. - 6.173 g.

REFERENCE VALUE: .1500 inch

OBSERVED ANGLE: 51°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1627	.1738	.1762	.1781	.1857	.1918	.1932	.1926	.1872	.1780	.1637
2	.1707	.2407	.2942	.3047	.3116	.3230	.3262	.3114	.3027	.2654	.1791
3	.1722	.3691	.4949	.5437	.5564	.5634	.5450	.5302	.4892	.3930	.1866
4	.1702	.4046	.6018	.6835	.6942	.6936	.6837	.6649	.5974	.4368	
5	.1860	.3882	.5270	.5906	.6136	.6199	.6229	.6207	.5429	.4048	
6	.1780	.2788	.3287	.3450	.3982	.4060	.4052	.3891	.3335	.2699	.1684
7	.1717	.1785								.1728	.1637

Slight shear, slight separation along one edge.

Table 1

SPECIMEN: Aluminum - .50 - #5

METHOD: Table

WEIGHT: 379.5 g.

MAX. GAGE DEFLECTION: .5048 inch

MAX. DEFLECTION: .3568 inch

THICKNESS: .1230 ± .0005 inch

EXPLOSIVE: .015 in. - 4.11 g.

REFERENCE VALUE: .1480 inch

OBSERVED ANGLE: 51°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1553	.1573	.1628	.1720	.1623	.1703	.1693	.1693	.1682	.1593	.1572
2	.1591	.2085	.2449	.2555	.2589	.2629	.2686	.2972	.2650	.2268	.1606
3	.1623	.2647	.3325	.3817	.4056	.4177	.4247	.4148	.3690	.2862	.1678
4	.1602	.2754	.3668	.4518	.4789	.4914	.5048	.5028	.4332	.4058	.1743
5	.1672	.2709	.3388	.3931	.4201	.4238	.4245	.4223	.3861	.3019	.1710
6	.1655	.2141	.2468	.2746	.2743	.2733	2728	.2648	.2643	.2425	.1743
7	.1607	.1757	.1803	.1833	.1833	.1881	.1859	.1833	.1781	.1738	.1663

Slight shear, off-center deflection.

Table 1

SPECIMEN: Steel - .75 - #1

METHOD: Table

WEIGHT: 1078.0 g.

MAX. GAGE DEFLECTION: .2096 inch

MAX. DEFLECTION: .0788 inch

THICKNESS: .1060 $\pm$ .0005 inch

EXPLOSIVE: .010 in. - 4.50 g.

REFERENCE VALUE: .1308 inch

OBSERVED ANGLE: Non-descript

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1319	.1515	.1495	.1495	.1497	.1497	.1493	.1492	.1884	.1415	.1291
2	.1326	.1521	.1526	.1533	.1553	.1599	.1618	.1664	.1618	.1503	.1295
3	.1288	.1506	.1546	.1585	.1646	.1741	.1864	.1928	.1878	.1621	.1385
4	.1306	.1531	.1478	.1631	.1714	.1836	.1961	.2022	.1964	.1670	.1353
5	.1373	.1488	.1532	.1616	.1722	.1871	.2018	.2096	.1964	.1698	.1363
6	.1351	.1556	.1524	.1578	.1656	.1784	.1906	.1998	.1911	.1692	.1363
7	.1341	.1397	.1412	.1451	.1541	.1668	.1754	.1800	.1775	.1584	.1351
8	.1341	.1386	.1403	.1411	.1426	.1451	.1458	.1438	.1431	.1406	.1331
9	.1331	.1375	.1392	.1396	.1406	.1416	.1387	.1368	.1316	.1310	.1297

Off-center deflection

Table 1

SPECIMEN: Steel - .75 - #2
METHOD: Table
WEIGHT: 1065.0 g.
MAX. GAGE DEFLECTION: .4576 inch
MAX. DEFLECTION: .3283 inch

THICKNESS: .1060 $\pm$ .0005 inch
EXPLOSIVE: .015 in. - 7.380 g.
REFERENCE VALUE: .1293 inch
OBSERVED ANGLE: 49°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1243	.1254	.1269	.1356	.1389	.1406	.1456	.1402	.1326	.1302	.1274
2	.1253	.1588	.1788	.1952	.2041	.2076	.2002	.1913	.1812	.1558	.1264
3	.1302	.2049	.2566	.2864	.3106	.3223	.3141	.2945	.2670	.2040	.1294
4	.1245	.2264	.3031	.3654	.4038	.4135	.4004	.3606	.3054	.2186	.1294
5	.1276	.2396	.3223	.3788	.4396	.4576	.4516	.3934	.3126	.2188	.1296
6	.1272	.2350	.3160	.3695	.4069	.4259	.4112	.3706	.3096	.2204	.1264
7	.1274	.2304	.2844	.3160	.3362	.3454	.3337	.3074	.2766	.2014	.1256
8	.1254	.1888	.2044	.2106	.2134	.2168	.2122	.2096	.2000	.1716	.1235
9	.1235	.1256	.1276	.1289	.1372	.1373	.1325	.1289	.1264	.1236	.1225

Slight shear

Table 1

SPECIMEN: Steel - .75 - #3
METHOD: Table
WEIGHT: 1059.8 g.
MAX. GAGE DEFLECTION: .5340 inch
MAX. DEFLECTION: .4047 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .020 in. - 8.960 g.
REFERENCE VALUE: .1293 inch
OBSERVED ANGLE: 48°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1326	.1370	.1488	.1413	.1428	.1488	.1440	.1430	.1378	.1368	.1308
2	.1320	.1942	.2184	.2354	.2442	.2572	.2359	.2346	.2226	.1908	.1338
3	.1294	.2317	.3053	.3431	.3728	.3903	.3813	.3543	.3.58	.2447	.1324
4	.1324	.2348	.3470	.4167	.4669	.4851	.4808	.4350	.3630	.2568	.1344
5	.1346	.2398	.4690	.4479	.5108	.5340	.5108	.4543	.3790	.2682	.1358
6	.1330	.2412	.3404	.4184	.4630	.4804	.4713	.4223	.3655	.2568	.1336
7	.1303	.2348	.3126	.3263	.3624	.3704	.3612	.3415	.3055	.2390	.1310
8	.1302	.1874	.2083	.2178	.2278	.2384	.2184	.2137	.2103	.1849	.1288
9	.1268	.1358	.1398	.1447	.1523	.1549	.1528	.1428	.1388	.1358	.1268

Slight shear

Table 1

SPECIMEN: Steel - .75 - #4
METHOD: Table
WEIGHT: 1067.8 g.
MAX. GAGE DEFLECTION: .8595 inch
MAX. DEFLECTION: .7106 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .030 in. - 14.395 g.
REFERENCE VALUE: .1485 inch
OBSERVED ANGLE: 48°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1339	.1355	.1389	.1381	.1516	.1529	.1489	.1479	.1469	.1460	.1369
2	.1437	.2591	.2875	.3175	.3224	.3325	.3199	.3159	.3139	.2639	.1429
3	.1579	.3274	.4646	.5069	.5280	.4485	.4248	.4115	.4501	.3325	.1479
4	.1534	.3599	.4365	.6621	.7371	.7684	.7426	.6577	.5281	.3709	.1529
5	.1627	.3587	.5611	.7181	.8227	.8595	.8175	.7248	.5747	.3632	.1648
6	.1547	.3547	.5395	.6581	.7139	.7341	.7143	.6417	.5215	.3351	.1535
7	.1504	.3310	.4643	.5041	.5243	.5299	.5147	.4991	.4355	.3186	.1447
8	.1459	.2755	.3227	.3294	.3183	.3209	.3169	.3124	.2847	.2385	.1409
9	.1506	.1595	.1609	.1669	.1769	.1809	.1769	.1549	.1527	.1489	.1350

Slight shear

Table 1

SPECIMEN: Steel - .75 - #5
METHOD: Table
WEIGHT: 1068.5 g.
MAX. GAGE DEFLECTION: .9113 inch
MAX. DEFLECTION: .7911 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .035 in. - 16.18 g.
REFERENCE VALUE: .1202 inch
OBSERVED ANGLE: 47°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1422	.1489	.1643	.1645	.1674	.1707	.1685	.1640	.1549	.1494	.1418
2	.1603	.2068	.2585	.3545	.3615	.3670	.3619	.3498	.3436	.2710	.1513
3	.1643	.4088	.5410	.5600	.5759	.5746	.5755	.5428	.4748	.4462	.1513
4	.1703	.4297	.6233	.7433	.8097	.8172	.7954	.6808	.5516	.4741	.1652
5	.1763	.4468	.6693	.8114	.8977	.9113	.8483	.7157	.5659	.3742	.1653
6	.1720	.4280	.6345	.5353	.7870	.8083	.7513	.6633	.5383	.3584	.1543
7	.1593	.4214	.5494	.5714	.5834	.5853	.5724	.5265	.4744	.3215	.1543
8	.1591	.2228	.3356	.3358	.3493	.3403	.3299	.3141	.3093	.2664	.1503
9	.1473										.1408

Slight shear

Table 1

SPECIMEN: Aluminum - .75 - #1

METHOD: Table

WEIGHT: 395.0 g.

MAX. GAGE DEFLECTION: .4085 inch

MAX. DEFLECTION: .2592 inch

THICKNESS: .1230 ± .0005 inch

EXPLOSIVE: .010 in. - 4.330 g.

REFERENCE VALUE: .1493 inch

OBSERVED ANGLE: 47°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1508	.1590	.1590	.1620	.1635	.1635	.1625	.1606	.1594	.1572	.1518
2	.1573	.1838	.2019	.2182	.2218	.2213	.2173	.2068	.1888	.1694	.1541
3	.1578	.2375	.2746	.2968	.3183	.3208	.3108	.2793	.2418	.1993	.1613
4	.1672	.2554	.3203	.3582	.3751	.3751	.3541	.3334	.2653	.2145	.1643
5	.1718	.2628	.3372	.3851	.4072	.4085	.3713	.3226	.3704	.2129	.1662
6	.1623	.2593	.3242	.3606	.3729	.3728	.3398	.2972	.2505	.2074	.1628
7	.1609	.2373	.2894	.3085	.3093	.2985	.2972	.2609	.2303	.1971	.1613
8	.1583	.2082	.2311	.2407	.2407	.2391	.2282	.2186	.1970	.1783	.1608
9	.1543	.1689	.1730	.1751	.1763	.1762	.1673	.1718	.1674	.1650	.1590

Table 1

SPECIMEN: Aluminum - .75 - #2

METHOD: Table

WEIGHT: 397.0 g.

MAX. GAGE DEFLECTION: .7019 inch

MAX. DEFLECTION: .5536 inch

THICKNESS: .1230 ± .0005 inch

EXPLOSIVE: .015 in. - 7.095 g.

REFERENCE VALUE: .1483 inch

OBSERVED ANGLE: 48°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1465	.1493	.1493	.1498	.1528	.1543	.1533	.1533	.1508	.1488	.1471
2	.1445	.2003	.2334	.2476	.2477	.2486	.2508	.2498	.2453	.2204	.1543
3	.1448	.2619	.3632	.4007	.4313	.4335	.4403	.4209	.3905	.3050	.1504
4	.1448	.2832	.4058	.5031	.5689	.6122	.5948	.5485	.4673	.4353	.1558
5	.1503	.3045	.4448	.5582	.6472	.7019	.6973	.6262	.5170	.3397	.1543
6	.1588	.2969	.4316	.5262	.6013	.6353	.6303	.5720	.4694	.3286	.1672
7	.1473	.2853	.3794	.4207	.4429	.4763	.4713	.4377	.4133	.3180	.1473
8	.1472	.2351	.2740	.2908	.3072	.3093	.3018	.3004	.2848	.2504	.1474
9	.1313	.1563	.1568	.1653	.1661	.1663	.1651	.1573	.1551	.1523	.1441

Slight shear

Table 1

SPECIMEN: Aluminum - .75 - #3

METHOD: Table

WEIGHT: 394.3 g.

MAX. GAGE DEFLECTION:

MAX. DEFLECTION:

THICKNESS: .1230 $\pm$ .0005 inch

EXPLOSIVE: .025 in. - 11.750 g.

REFERENCE VALUE:

OBSERVED ANGLE:

y \ x	1	2	3	4	5	6	7	8	9	10	11
1											
2											
3											
4											
5											
6											
7											
8											
9											

Completely sheared, total separation.

Table 1

SPECIMEN: Aluminum - .75 - #4

METHOD: Table

WEIGHT: 400.0 g.

MAX. GAGE DEFLECTION: .6857 inch

MAX. DEFLECTION: .5577 inch

THICKNESS: .1230 ± .0005 inch

EXPLOSIVE: .020 in. - 8.250 g.

REFERENCE VALUE: .1280 inch

OBSERVED ANGLE: 49°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1466	.1483	.1491	.1518	.1523	.1623	.1518	.1511	.1490	.1473	.1712
2	.1523	.2191	.2530	.2655	.2768	.2816	.2763	.2636	.2276	.1812	.1480
3	.1523	.2828	.3622	.4141	.4330	.4388	.4352	.3785	.3173	.2335	.1513
4	.1503	.2131	.4570	.5535	.6127	.6253	.5741	.4765	.3968	.2772	.1575
5	.1551	.3272	.4966	.6275	.6815	.6857	.6207	.5205	.4214	.2838	.1836
6	.1533	.3224	.4762	.5570	.6096	.6121	.5734	.4935	.4156	.2858	.1613
7	.1533	.3203	.4018	.4390	.4663	.4758	.4445	.4083	.3543	.2484	.1481
8	.1585	.2638	.2717	.2792	.2944	.2954	.2938	.2680	.2392	.2018	.1473
9	.1533	.1453	.1593	.1643	.1731	.1743	.1573	.1551	.1528	.1479	.1403

Slight shear, off-center deflection.

Table 1

SPECIMEN: Aluminum - .75 - #5

METHOD: Table

WEIGHT: 421.8 g.

MAX. GAGE DEFLECTION: .6633 inch

MAX. DEFLECTION: .5132 inch

THICKNESS: .1230 $\pm$ .0005 inch

EXPLOSIVE: .015 in. - 6.560 g.

REFERENCE VALUE: .1501 inch

OBSERVED ANGLE: 49°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1442	.1494	.1531	.1538	.1634	.1638	.1608	.1518	.1510	.1494	.1470
2	.1508	.2018	.2441	.2702	.2767	.2790	.2813	.2796	.2730	.2683	.1679
3	.1513	.2423	.3484	.3954	.4168	.4370	.4413	.4351	.4063	.3428	.1483
4	.1613	.2599	.4119	.4870	.5397	.5870	.5894	.5482	.4707	.3475	.1763
5	.1651	.2794	.4197	.5441	.6080	.6593	.6633	.6230	.5148	.3643	.1625
6	.1573	.2735	.4230	.5195	.5768	.6039	.6153	.5978	.4982	.3564	.1573
7	.1593	.2534	.3811	.4504	.4684	.5055	.4993	.4907	.4466	.3619	.1493
8	.1573	.2235	.2739	.2963	.2993	.3148	.3123	.2972	.2833	.2696	.1480
9	.1498										.1488

Large shear, slight separation and translation.

Table 1

SPECIMEN: Steel - 1.00 - #1
METHOD: Table
WEIGHT: 1321.0 g.
MAX. GAGE DEFLECTION: .3100 inch
MAX. DEFLECTION: .1670 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .010 in. - 5.985 g.
REFERENCE VALUE: .1430 inch
OBSERVED ANGLE: Non-descript

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1480	.1525	.1579	.1580	.1600	.1630	.1625	.1598	.1515	.1510	.1458
2	.1515	.1691	.1815	.1848	.1852	.1894	.1925	.1880	.1815	.1700	.1546
3	.1642	.1854	.2085	.2130	.2144	.2196	.2258	.2205	.2156	.1895	.1491
4	.1635	.1938	.2242	.2327	.2402	.2530	.2592	.2558	.2380	.1955	.1460
5	.1560	.1979	.2335	.2490	.2655	.2894	.2945	.2814	.2530	.2158	.1508
6	.1620	.2010	.2365	.2593	.2816	.3096	.3100	.2871	.2560	.2104	.1500
7	.1610	.1996	.2374	.2592	.2810	.2979	.3005	.2822	.2538	.2074	.1500
8	.1580	.1944	.2296	.2477	.2594	.2695	.2690	.2658	.2444	.2032	.1485
9	.1610	.1900	.2174	.2306	.2355	.2384	.2372	.2338	.2180	.1904	.1471
10	.1580	.1784	.1907	.1935	.1935	.1930	.1905	.1892	.1861	.1710	.1460
11	.1548	.1584	.1640	.1605	.1610	.1617	.1610	.1532	.1482	.1461	.1449

Table 1

SPECIMEN: Steel - 1.00 - #2
METHOD: Table
WEIGHT: 1198.0 g.
MAX. GAGE DEFLECTION: .5409 inch
MAX. DEFLECTION: .3908 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .015 in. - 9.755 g.
REFERENCE VALUE: .1501 inch
OBSERVED ANGLE: 45°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1452	.1495	.1504	.1544	.1565	.1578	.1464	.1462	.1458	.1428	.1428
2	.1494	.1923	.2044	.2378	.2414	.2440	.2384	.2315	.2275	.2036	.1426
3	.1516	.2309	.2840	.3119	.3292	.3373	.3236	.3164	.2949	.2316	.1464
4	.1560	.2357	.3095	.3138	.4015	.4321	.4275	.3909	.3964	.2667	.1494
5	.1524	.2451	.3264	.3939	.4655	.5073	.4927	.4355	.3576	.2620	.1594
6	.1634	.2462	.3226	.4171	.4891	.5409	.5254	.4509	.3536	.2765	.1624
7	.1594	.2406	.3242	.3995	.4836	.5134	.4996	.4462	.3524	.2614	.1534
8	.1534	.2369	.3108	.3665	.4119	.4477	.4336	.3914	.3356	.2735	.1610
9	.1529	.2194	.2799	.3149	.3350	.3535	.3446	.3309	.3093	.2600	.1511
10	.1494	.1975	.2240	.2370	.2576	.2596	.2502	.2446	.2465	.2209	.1589
11	.1451	.1494	.1563	.1530	.1552	.1674	.1551	.1524	.1488	.1494	.1424

Table 1

SPECIMEN: Steel - 1.00 - #3
METHOD: Table
WEIGHT: 1326.0 g.
MAX. GAGE DEFLECTION: .5983 inch
MAX. DEFLECTION: .4577 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .020 in. - 12.405 g.
REFERENCE VALUE: .1406 inch
OBSERVED ANGLE: 45°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1494	.1576	.1604	.1634	.1644	.1662	.1574	.1561	.1551	.1524	.1514
2	.1630	.2129	.2363	.2509	.2618	.2634	.2408	.2246	.2176	.1911	.1494
3	.1562	.2488	.3134	.3560	.3546	.3335	.3376	.3146	.2746	.2159	.1474
4	.1604	.2699	.3507	.4076	.4580	.4786	.4509	.3939	.3197	.2606	.1485
5	.1624	.2639	.3708	.4593	.5241	.5619	.5197	.4386	.3734	.2579	.1474
6	.1676	.2905	.3974	.4885	.5764	.5983	.5428	.4624	.3708	.2624	.1539
7	.1544	.2786	.3864	.4876	.5512	.5607	.5310	.4559	.3658	.2620	.1476
8	.1504	.2826	.3644	.4316	.4886	.5000	.4720	.4230	.3536	.2636	.1473
9	.1524	.2644	.3284	.3669	.3774	.3899	.3804	.3559	.3207	.2499	.1474
10	.1514	.2376	.2644	.2654	.2759	.2854	.2760	.2609	.2506	.2161	.1474
11	.1574	.1656	.1676	.1673	.1685	.1695	.1672	.1651	.1552	.1494	.1462

Slight shear

Table 1

SPECIMEN: Steel - 1.00 - #4
METHOD: Table
WEIGHT: 1333.5 g.
MAX. GAGE DEFLECTION: 1.0052 inch
MAX. DEFLECTION: .8454 inch

THICKNESS: .1060 ± .0005 inch
EXPLOSIVE: .025 in. - 17.795 g.
REFERENCE VALUE: .1598 inch
OBSERVED ANGLE: 45°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1498	.1658	.1758	.1778	.1768	.1778	.1771	.1773	.1644	.1588	.1548
2	.1618	.3092	.3614	.3718	.3935	.3816	.3761	.3689	.3709	.3334	.1676
3	.1628	.3472	.4684	.5416	.5734	.5698	.5648	.5507	.4891	.3693	.1681
4	.1708	.3623	.5190	.6369	.7362	.7895	.7362	.6799	.5498	.3735	.1748
5	.1748	.3595	.5428	.7137	.8562	.9130	.8773	.7621	.5942	.4129	.1738
6	.1778	.2802	.5572	.7380	.9258	1.0052	.9530	.8110	.6025	.3835	.1778
7	.1758	.3767	.5463	.7248	.8365	.9277	.8799	.7634	.5675	.4155	.1768
8	.1718	.3665	.5258	.6476	.7209	.7799	.6435	.6688	.5640	.3935	.1728
9	.1668	.3463	.4906	.5370	.5734	.5758	.5628	.5550	.4907	.3549	.1671
10	.1628	.2854	.3638	.3639	.3776	.3909	.3876	.3798	.3453	.3035	.1640
11	.1488	.1618	.1728	.1708	.1738	.1748	.1698	.1698	.1674	.1578	.1528

Slight shear

Table 1

SPECIMEN: Steel - 1.00 - #5
METHOD: Table
WEIGHT: 1331.5 g.
MAX. GAGE DEFLECTION: 1.1375 inch
MAX. DEFLECTION: .9869 inch

THICKNESS: .1060 $\pm$ .0005 inch
EXPLOSIVE: .035 in. - 22.595 g.
REFERENCE VALUE: .1506 inch
OBSERVED ANGLE: 45°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1742	.1956	.2085	.2105	.2110	.2115	.2095	.2115	.2120	.2015	.1715
2	.2085	.3532	.4005	.4119	.4310	.4320	.4315	.4305	.4243	.3657	.2049
3	.2063	.4306	.5432	.6136	.6356	.6578	.6510	.6375	.5840	.4406	.2163
4	.2132	.4326	.5968	.7263	.8243	.8584	.8347	.7650	.6442	.4472	.2163
5	.2165	.4970	.6284	.8241	.9641	1.0261	.9860	.8280	.6456	.4522	.1985
6	.2165	.4432	.6420	.8680	1.0393	1.1375	1.0425	.8717	.6469	.4334	.1977
7	.2153	.4358	.6286	.8365	.9750	1.0540	.9916	.8332	.6449	.4286	.2063
8	.2120	.4332	.5939	.7303	.8143	.8143	.8412	.7543	.6305	.4139	.1990
9	.2085	.4033	.5316	.6136	.6502	.6523	.6465	.6232	.5603	.4122	.1979
10	.2175	.3625	.4201	.4425	.4540	.4550	.4425	.4195	.4316	.3435	.1963
11	.1745	.1998	.2115	.2120	.2122	.2123	.2113	.2097	.2065	.2008	.1755

Table 1

SPECIMEN: Aluminum - 1.00 - #1
METHOD: Table
WEIGHT: 501.6 g.
MAX. GAGE DEFLECTION: .5236 inch
MAX. DEFLECTION: .3736 inch

THICKNESS: .1230 $\pm$ .0005 inch
EXPLOSIVE: .010 in. - 6.020 g.
REFERENCE VALUE: .1500 inch
OBSERVED ANGLE: 45°

Y \ X	1	2	3	4	5	6	7	8	9	10	11
1	.1665	.1690	.1678	.1677	.1680	.1678	.1624	.1714	.1694	.1704	.1439
2	.1698	.2302	.2411	.2453	.2477	.2493	.2502	.2486	.2429	.2175	.1509
3	.1599	.2504	.2983	.3059	.3229	.3268	.3257	.3205	.3015	.2534	.1509
4	.1749	.2611	.3083	.3544	.3828	.4100	.4000	.3704	.3300	.2636	.1599
5	.1799	.2700	.3189	.3878	.4403	.4783	.4673	.4053	.3436	.2681	.1657
6	.1789	.2625	.3309	.4275	.4929	.5236	.4859	.4213	.3510	.2690	.1639
7	.1760	.2663	.3379	.4053	.4674	.4948	.4636	.4038	.3451	.2678	.1639
8	.1725	.2615	.3187	.2710	.4085	.4159	.4071	.3702	.3274	.2615	.1609
9	.1709	.2671	.2975	.3124	.3250	.3366	.3277	.3184	.3021	.2494	.1557
10	.1581	.2266	.2406	.2518	.2509	.2514	.2518	.2411	.2394	.2077	.1499
11	.1564	.1699	.1829	.1829	.1831	.1831	.1819	.1786	.1777	.1735	.1478

Table 1

SPECIMEN: Aluminum - 1.00 - #2 THICKNESS: .1230 ± .0005 inch

METHOD: Table EXPLOSIVE: .015 in. - 9.120 g.

WEIGHT: 504.0 g. REFERENCE VALUE: .1571 inch

MAX. GAGE DEFLECTION: .8563 inch OBSERVED ANGLE: 45°

MAX. DEFLECTION: .6992 inch

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1504	.1478	.1548	.1643	.1583	.1633	.1662	.1656	.1603	.1496	.1390
2	.1573	.2448	.2793	.3075	.3130	.3213	.3190	.3149	.2939	.2733	.1574
3	.1628	.2798	.3842	.4330	.4624	.4820	.4911	.4838	.4306	.3218	.1598
4	.1598	.2933	.4130	.4236	.5936	.6432	.6348	.5899	.4864	.3410	.1688
5	.1608	.2983	.3330	.5681	.6896	.6718	.6542	.6700	.5213	.3553	.1648
6	.1733	.3172	.4450	.6023	.7425	.8563	.8183	.7104	.5430	.3447	.1728
7	.1588	.3104	.4450	.6004	.7148	.8018	.7818	.6810	.5345	.3850	.1678
8	.1598	.3020	.3082	.5053	.5793	.6269	.6310	.5860	.5084	.3670	.1657
9	.1556	.2767	.3783	.4314	.4630	.5008	.5018	.4918	.4553	.3543	.1528
10	.1523	.2440	.2894	.3040	.3384	.3514	.3456	.3398	.3386	.3072	.1508
11	.1528	.1619	.1649	.1779	.1913	.1756	.1716	.1698	.1556	.1556	.1592

Slight shear

Table 1

SPECIMEN: Aluminum - 1.00 - #3 THICKNESS: .1230 ± .0005 inch

METHOD: Table EXPLOSIVE: .020 in. - 12.375 g.

WEIGHT: 501.8 g. REFERENCE VALUE:

MAX. GAGE DEFLECTION: OBSERVED ANGLE:

MAX. DEFLECTION:

y \ x	1	2	3	4	5	6	7	8	9	10	11
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											

Completely sheared, total separation.

Table 1

SPECIMEN: Aluminum - 1.00 - #4

METHOD: Table

WEIGHT: 505.0 g.

MAX. GAGE DEFLECTION: .7520 inch

MAX. DEFLECTION: .6075 inch

THICKNESS: .1230 ± .0005 inch

EXPLOSIVE: .015 in. - 9.005 g.

REFERENCE VALUE: .1445 inch

OBSERVED ANGLE: 45°

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1584	.1689	.1744	.1854	.1842	.1984	.1942	.1862	.1836	.1804	.1724
2	.1675	.2377	.2852	.3100	.3411	.3663	.3722	.3685	.3610	.3378	
3	.1682	.2700	.3594	.4236	.4771	.5060	.5309	.5256	.4870	.4094	
4	.1704	.3036	.4022	.5040	.5804	.6181	.6449	.6320	.5718	.4494	
5	.1702	.3116	.4359	.5404	.6224	.7039	.7285	.6918	.6102	.4863	
6	.1731	.3242	.4351	.5407	.6584	.7520	.7121	.6124	.6076	.4698	
7	.1719	.3132	.4253	.5304	.6072	.6856	.7095	.6772	.5791	.4336	
8	.1684	.2862	.3889	.4822	.5485	.5919	.6224	.6019	.5519	.4953	
9	.1674	.2659	.3196	.4002	.4243	.4856	.4981	.4931	.4336	.3456	
10	.1662	.2339	.2683	.3071	.3339	.3476	.3424	.3384	.3214	.2985	.1764
11	.1571	.1663	.1806	.1826	.1842	.1944	.1829	.1784	.1764	.1762	.1724

Slight shear, separation along one edge, off-center deflection

Table 1

SPECIMEN: Aluminum - 1.00 - #5 THICKNESS: .1230 ± .0005 inch

METHOD: Table EXPLOSIVE: .015 in. - 8.950 g.

WEIGHT: 535.0 g. REFERENCE VALUE: .1445 inch

MAX. GAGE DEFLECTION: .7505 inch OBSERVED ANGLE: 45°

MAX. DEFLECTION: .6060 inch

y \ x	1	2	3	4	5	6	7	8	9	10	11
1	.1520	.1546	.1514	.1584	.1634	.1632	.1600	.1560	.1525	.1532	.1520
2	.1528	.2232	.2594	.2760	.2891	.2951	.2915	.2802	.2846	.2712	.1648
3	.1540	.2738	.3393	.3762	.4138	.4479	.4216	.4281	.4079	.3276	.1692
4	.1671	.2795	.3891	.4736	.5542	.5915	.5792	.5240	.4529	.3442	.1735
5	.1680	.2933	.4174	.5414	.6544	.6885	.6692	.5802	.4695	.3380	.1710
6	.1710	.2978	.4341	.5689	.7040	.7505	.7346	.6327	.5034	.5440	.1760
7	.1700	.2985	.4403	.5558	.6572	.7201	.6968	.6098	.4869	.3405	.1728
8	.1600	.2832	.4084	.5024	.5810	.6075	.5985	.5495	.4676	.3279	.1700
9	.1590	.2781	.3714	.4217	.4707	.4898	.4832	.4561	.4358	.3392	.1560
10	.1538	.2467	.2935	.3101	.3216	.3442	.3295	.3230	.3215	.3035	.1515
11	.1480	.1610	.1570	.1500	.1590	.1645	.1548	.1538	.1510	.1495	.1471

Table 1

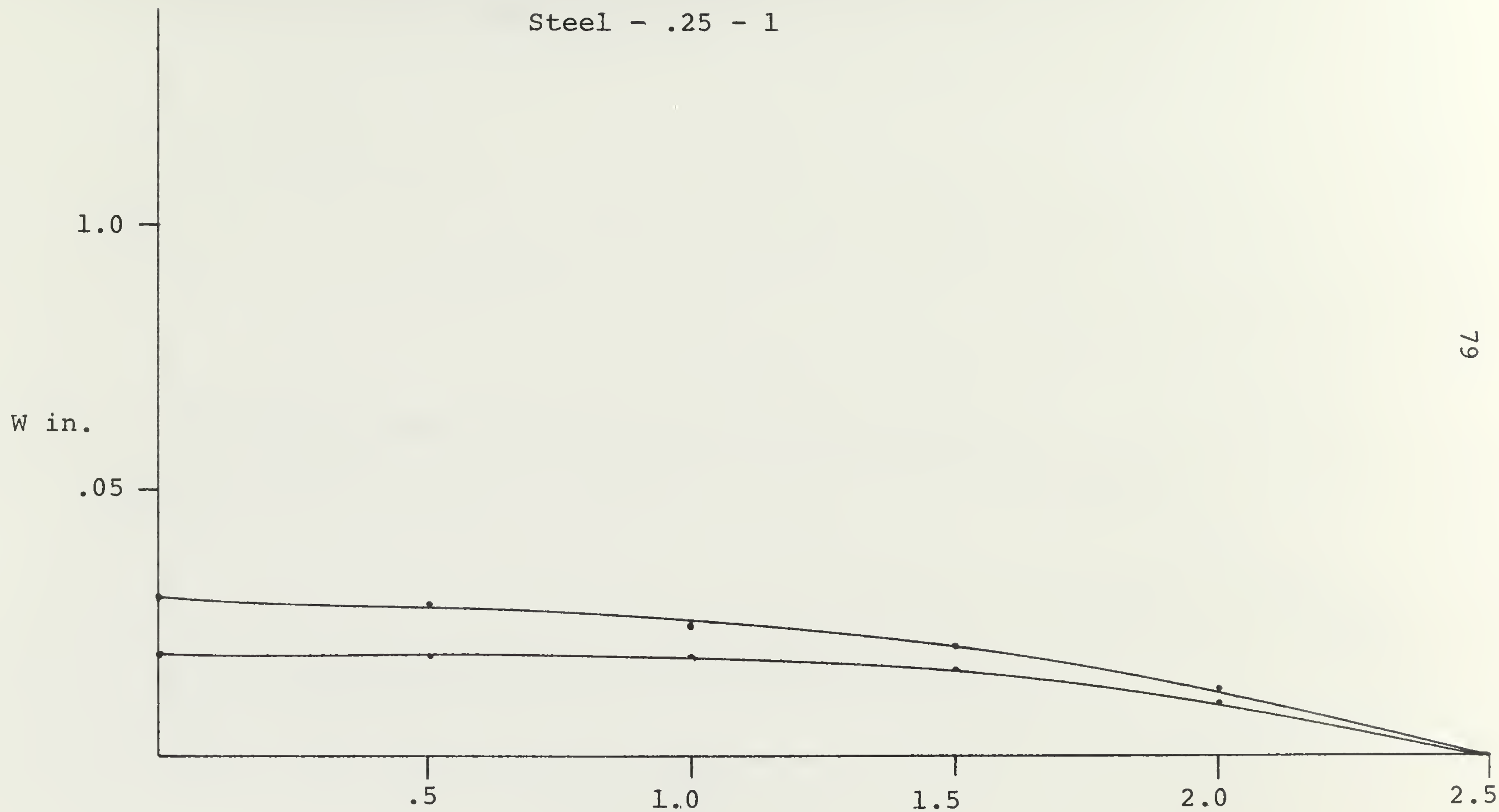


Figure 8

Aluminum - .25 - 5

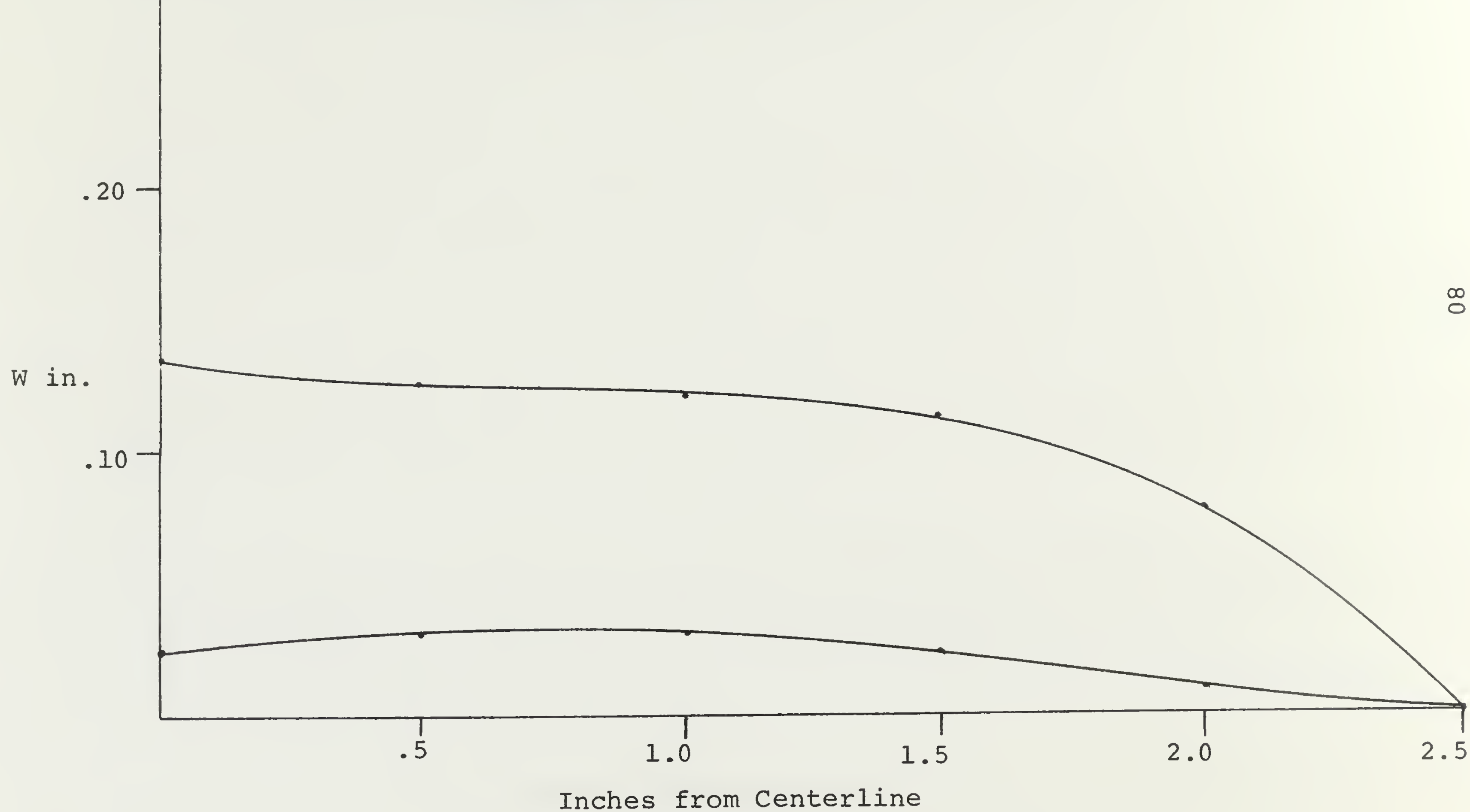


Figure 9

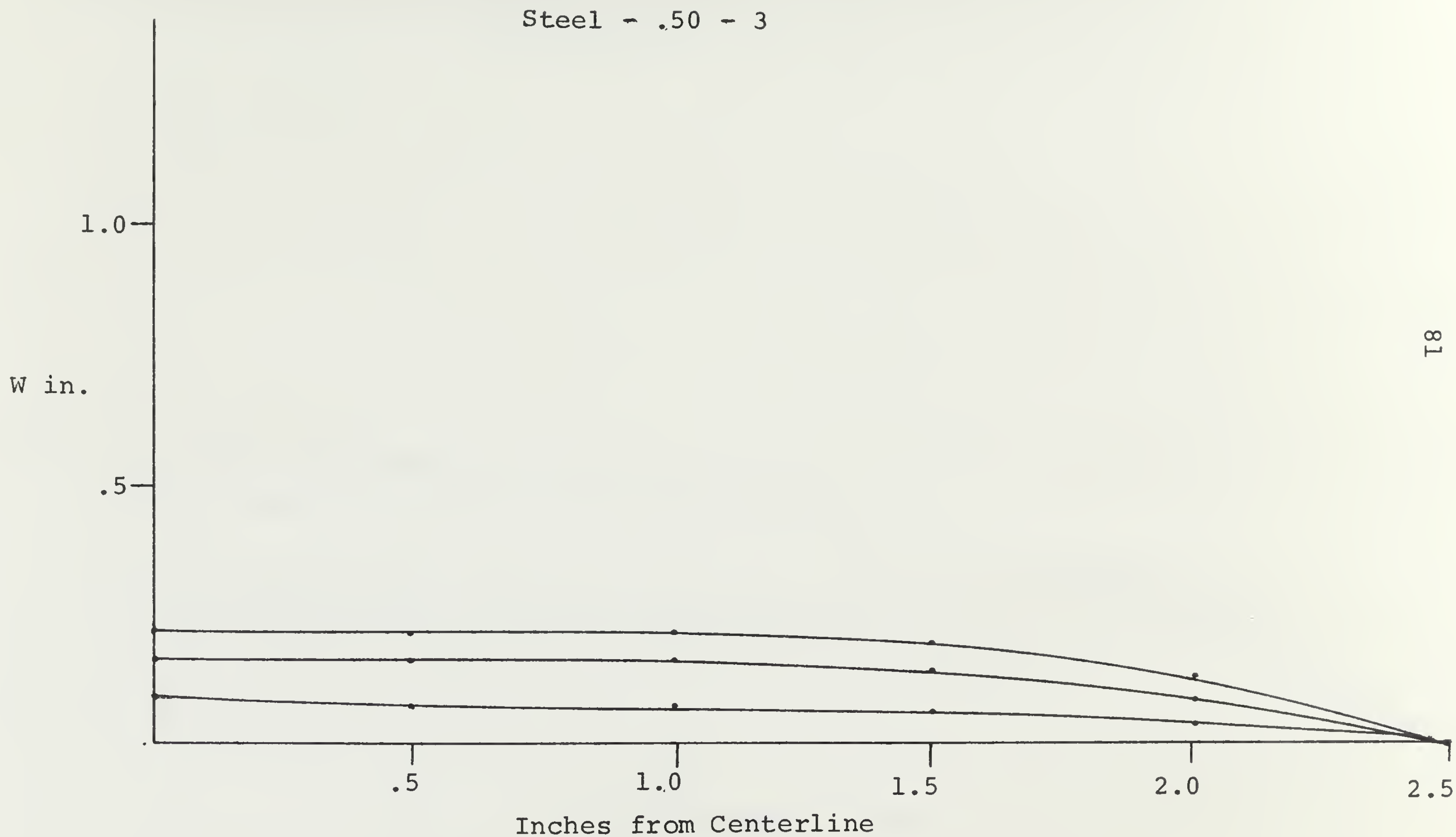


Figure 10

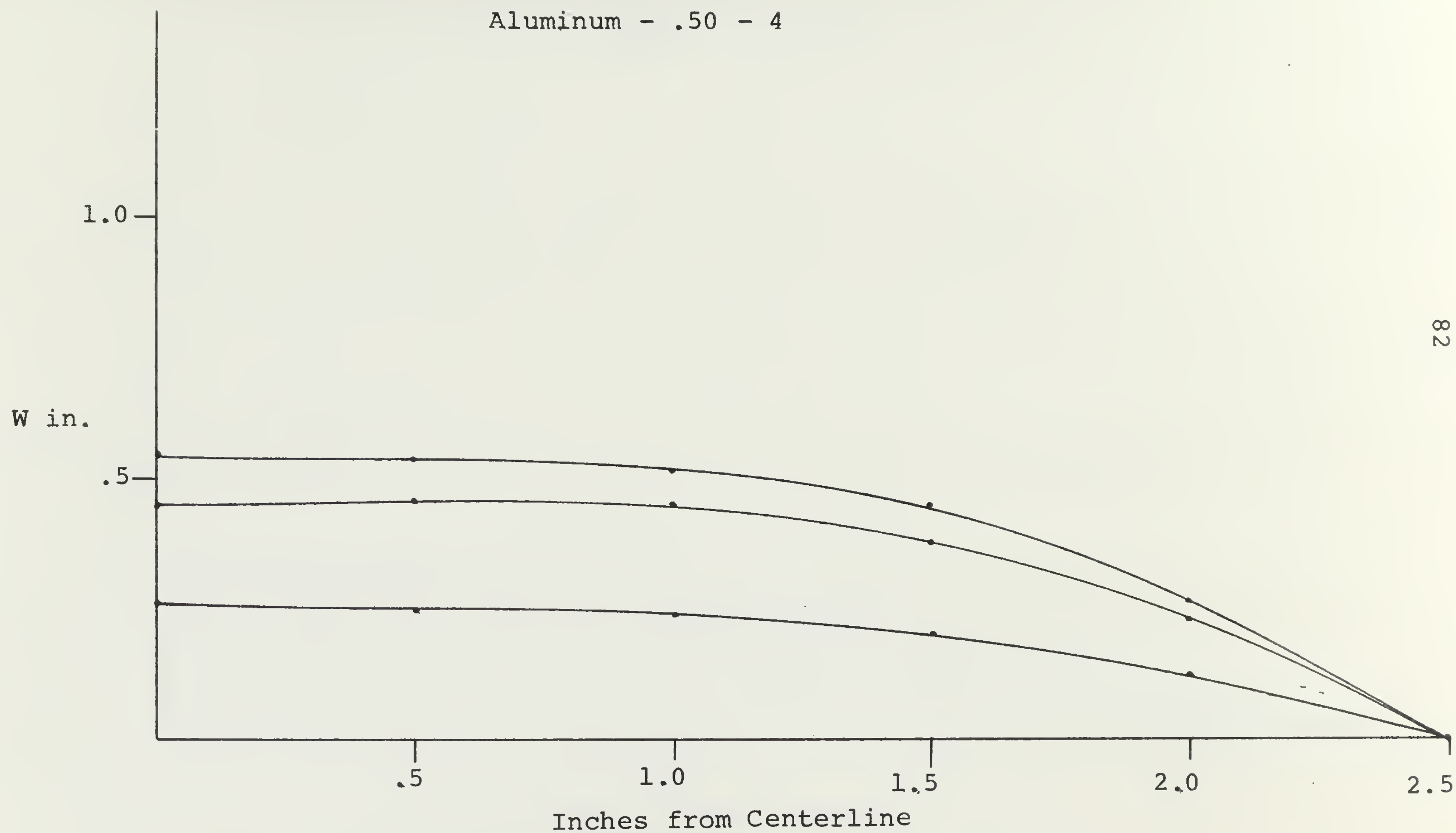


Figure 11

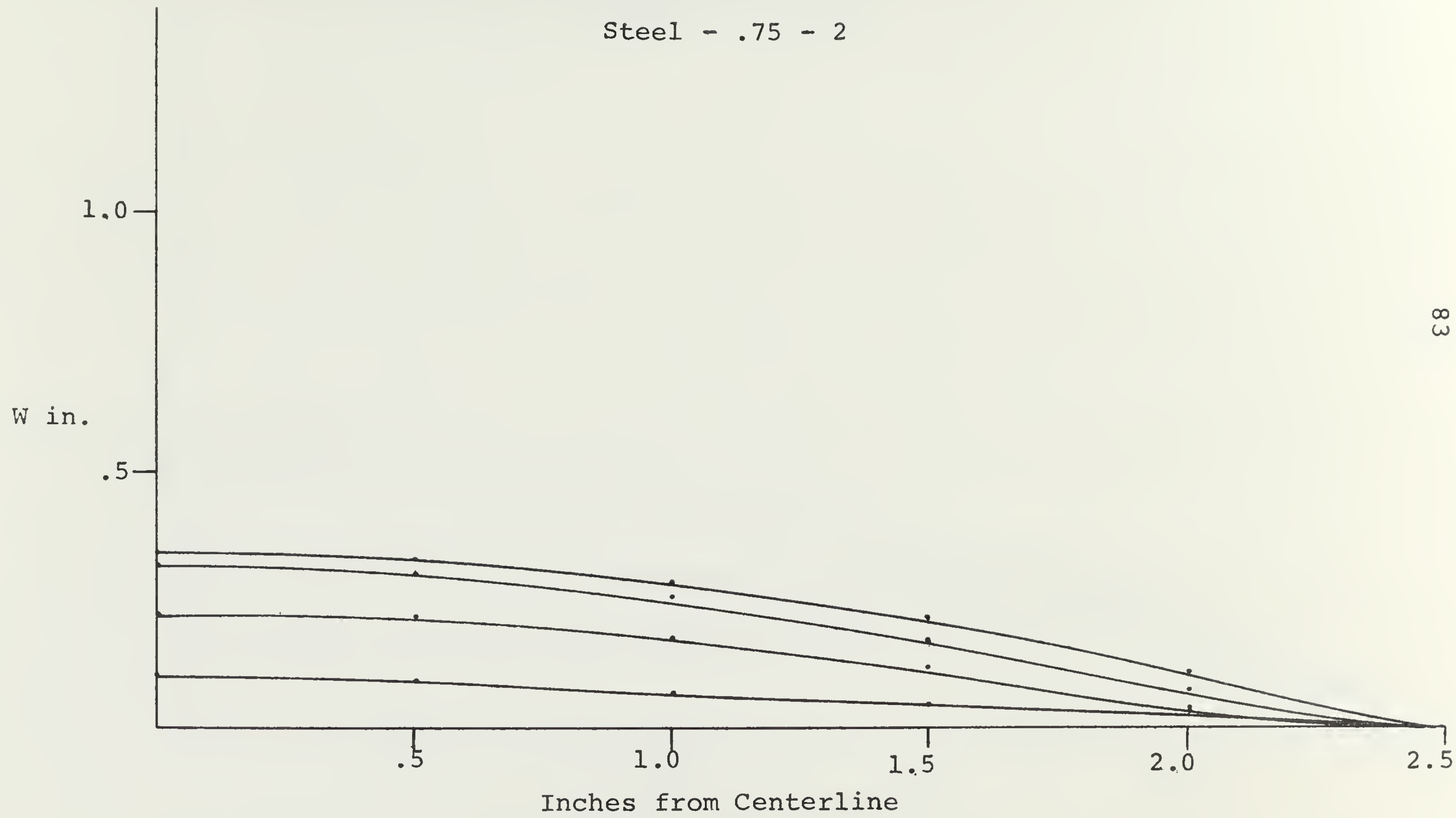


Figure 12

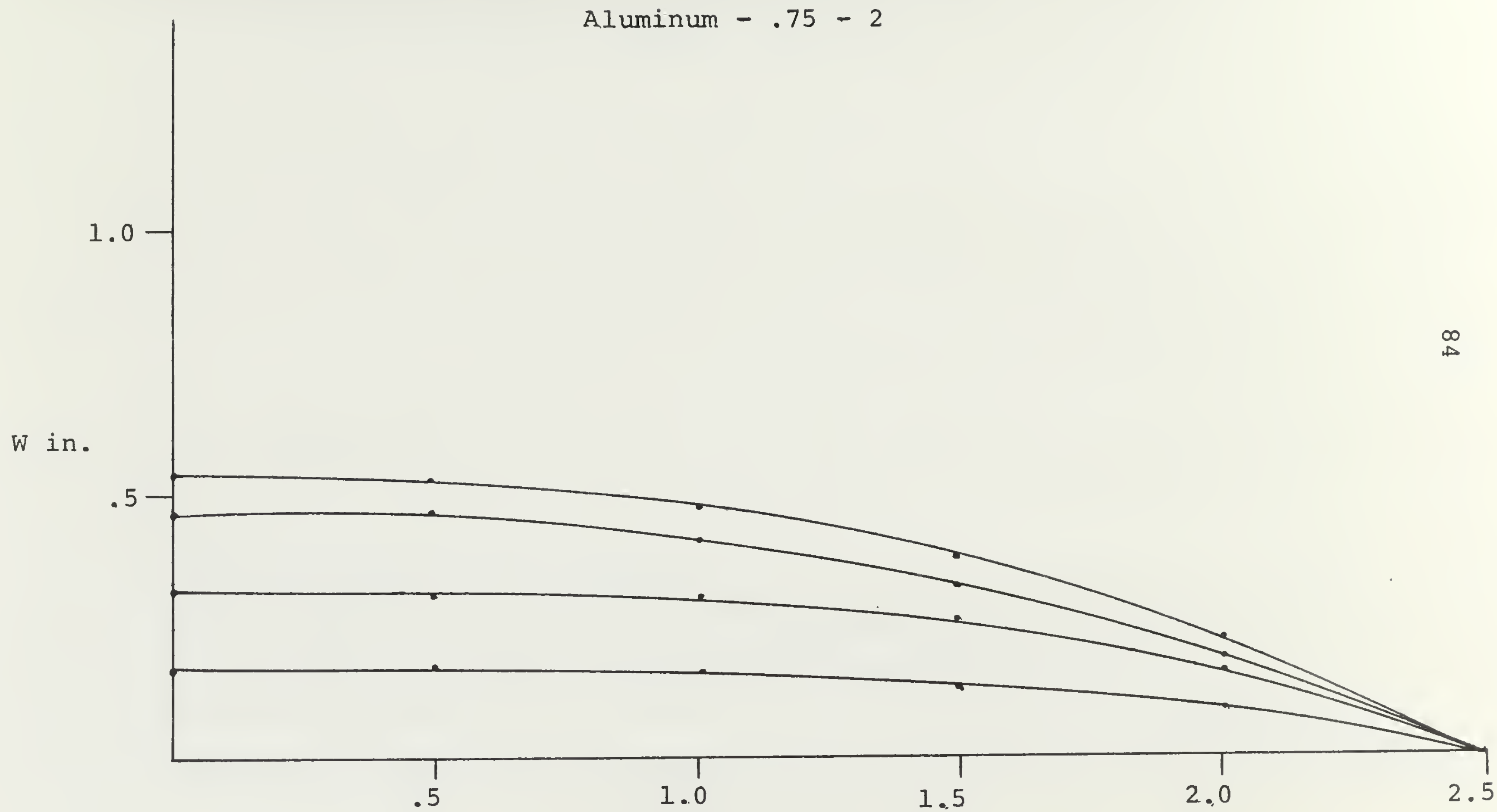


Figure 13

Steel - 1.00 - 2

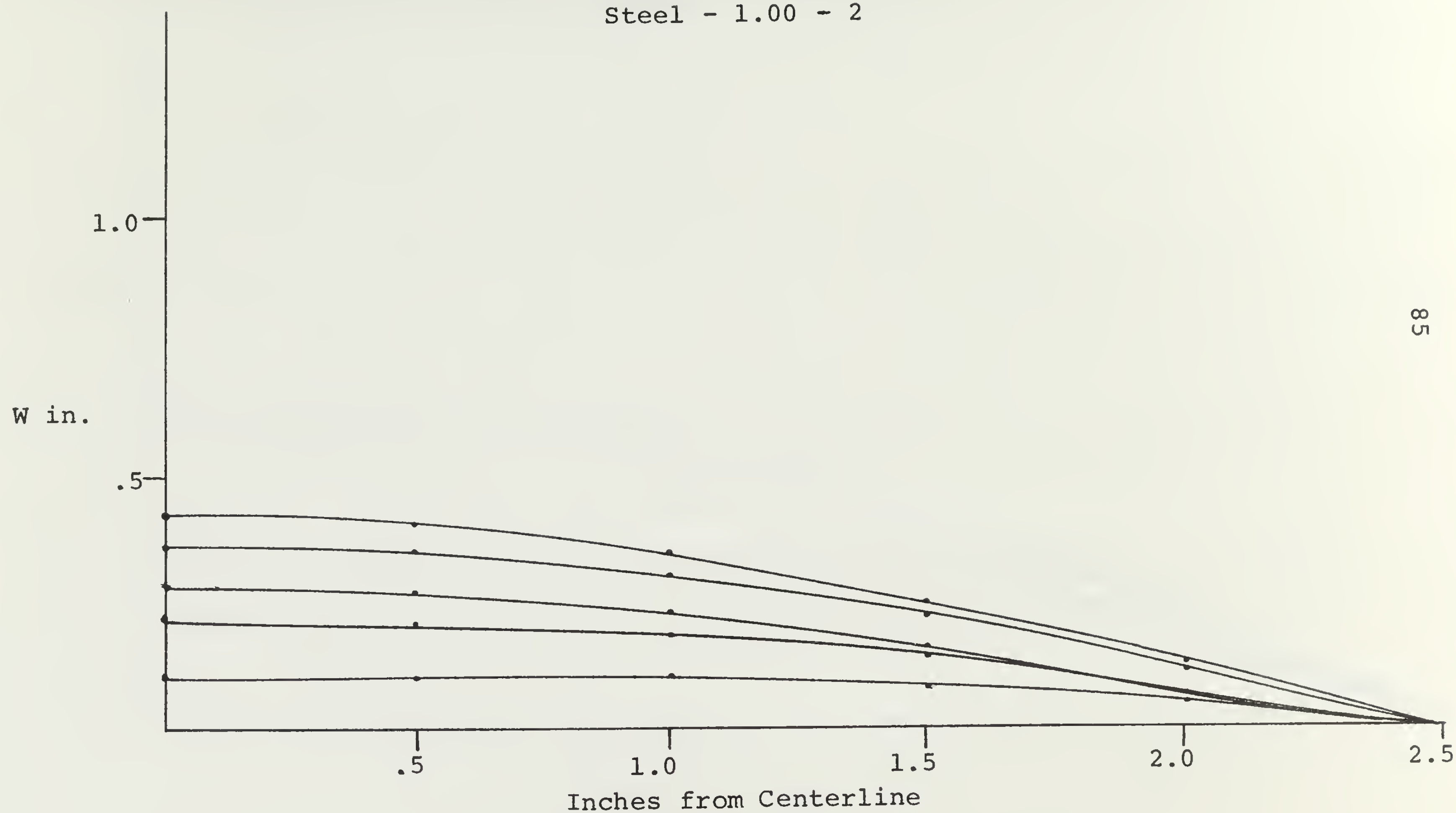


Figure 14

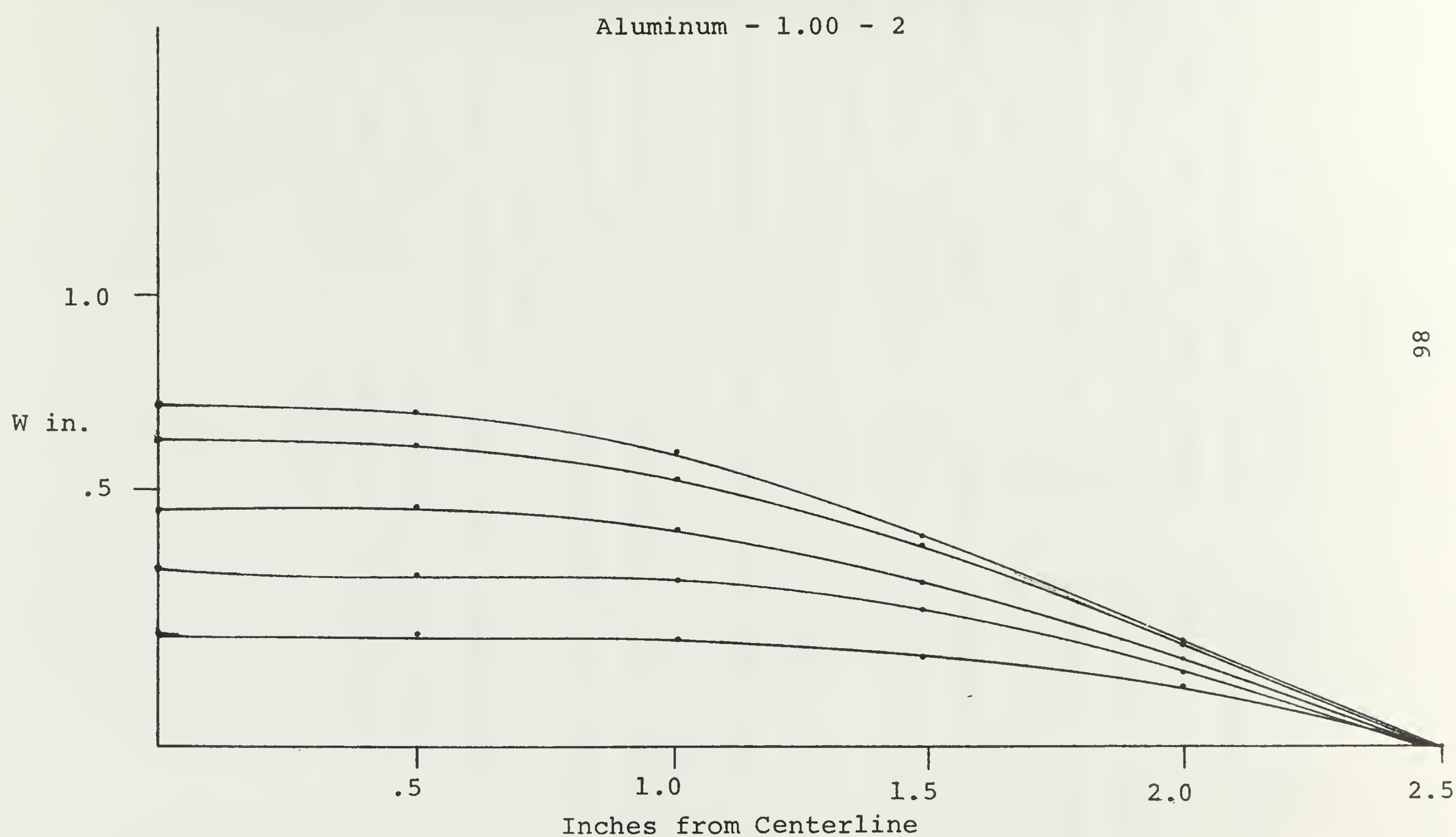


Figure 15

APPENDIX C

Tensile tests were conducted on an Instron testing machine to determine the yield stress σ_o. Two samples of each material were used, cut such that the major axis of both specimens would lie at 90° to each other with respect to the original plate from which all of the specimen plates were cut. This would account for any major differences in strength and would reveal a non-isotropic behavior on the specimen plate. The results clearly indicate that this was not the case.

The yield stresses were determined and used as the limiting stresses at which the stress was proportional to strain. In the case of aluminum alloys, a .2 per cent offset or a plastic strain of .002 must be used to determine the yield stress of the material due to an increase in strain above the proportional value.

Each sample was one-half inch wide, and the strain gauges were placed at a two inch range on the tensile specimen. Steel plate thickness was .106 inch and aluminum plate thickness was .1230 inch.

Mechanical Properties

Material	Thickness (in)	Yield Stress σ_o (psi)	Ultimate Stress σ_u (psi)	Elongation ε (in)	% Elongation %
Steel #1	.106	36,300	45,300	.508	25.4
Steel #2	.106	36,500	44,800	.506	25.3
Aluminum #1	.1230	40,800	44,800	.250	12.5
Aluminum #2	.1230	40,200	43,600	.242	12.1

Table 2

APPENDIX D

The initial velocity V_o in/sec is found in the calibration parameter of the explosive.

$$\text{Parameter} = \frac{18.42 \times 10^4 \text{ dynes - sec}}{\text{g. - wt. of explosive}}$$

$$\text{Total Impulse} = \text{Parameter} \times \text{Grams of Explosive}$$

$$V_o \text{ in/sec} = \text{Parameter} \times \text{Grams of Explosive} \times \frac{1}{\text{g. of specimen plate target}}$$

$$V_o \text{ (in/sec)} = \frac{18.42 \times 10^4 \text{ dynes sec}}{\text{g. wt. of explosive}} \times \frac{\text{explosive wt. g.}}{\text{specimen wt. g.}} \times \frac{1}{2.54 \text{ cm}}$$

The parameter λ is used as a non-dimensional relationship for the plotting of W_{max}/H versus energy imparted.

$$\lambda = \frac{\rho V_o^2 L^2}{M_o}$$

where

$$M_o = \frac{\sigma_o H^2}{4}$$

$$\rho = \text{mass density (lbm/in}^3\text{)}$$

hence

$$\lambda = \frac{\rho V_o^2 L^2}{M_o} = V_o^2 \left[\frac{4\rho L^2}{\sigma_o H^2}\right]$$

Table 3	This is a summary of the calculated V_o (in/sec), W_{max}/H, λ, and $\beta\lambda$ for each plate.
Figure 16	This is a plot of W_{max}/H versus V_o in/sec for each aspect ratio of the steel specimens.
Figure 17	This is a plot of W_{max}/H versus V_o in/sec for each aspect ratio of the aluminum specimens.
Figure 18	This is a plot of W_{max}/H versus the parameter λ for each aspect ratio of the steel specimens. The dashed line is a representation of the results of [8] for mild steel of aspect ratio .593.
Figure 19	This is a plot of W_{max}/H versus the parameter λ for each aspect ratio of the aluminum specimens. The dashed line is a representation of the results of [8] for aluminum 6061-T6 of aspect ratio .593.
Figures 20-23	These are the plots of W_{max}/H versus the parameter λ for each of the aspect ratios labeled. The dashed lines are a representation of the predictions of a Tresca solution for fully clamped rectangular plates subjected to uniformly distributed dynamic pressures from [9].
Figure 24	This is a representation of the correspondance of W_{max}/H versus the parameter $\beta\lambda$, where β is the aspect ratio, for mild steel.

Figure 25 This is a representation of the correspondance of W_{max}/H versus the parameter $\beta\lambda$, where β is the aspect ratio, for aluminum 6061-T6.

Table 4 This is a summary table of the angle ϕ predicted by the equation

$$\phi = \tan^{-1}\{(3 + \beta^2)^{1/2} - \beta\}$$

and the observed angles described in Table 1.

Specimen	Weight of Explosive in g.	$\frac{\text{Explosive wt. g.}}{\text{Specimen wt. g.}}$	V_o in/sec	W_{max}	W_{max}/H	λ	$\beta\lambda$
Steel-.25							
1	1.500	1.83×10^{-2}	1325	.0320	.301	76.2	19.0
2	2.400	2.93×10^{-2}	2110	.0683	.644	193.0	48.3
3	3.100	3.79×10^{-2}	2730	.0779	.736	322.0	80.5
4	5.470	6.66×10^{-2}	4820	.1997	1.882	101.0	252.0
5	3.605	4.40×10^{-2}	3200	.1260	1.190	445.0	111.0
Aluminum-.25							
1	1.510	4.59×10^{-2}	3330	.0608	.494	110.5	27.7
2	2.355	7.14×10^{-2}	5170	.1634	1.330	267.0	66.7
3	3.035	9.24×10^{-2}	6700	.2005	1.630	448.0	112.0
4	3.825	11.62×10^{-2}	8420	*	*	*	*
5	2.165	6.59×10^{-2}	4780	.1464	1.192	228.0	57.0

Table 3

Specimen	Weight of Explosive in g.	$\frac{\text{Explosive wt. g.}}{\text{Specimen wt. g.}}$	V_o in/sec	W_{max}	W_{max}/H	λ	$\beta\lambda$
Steel-.50							
1	3.280	2.00×10^{-2}	1452	.0828	.782	91.5	45.7
2	4.515	2.75×10^{-2}	1997	.1799	1.695	173.0	86.5
3	5.910	3.60×10^{-2}	2610	.2175	2.050	296.0	148.0
4	9.010	5.49×10^{-2}	3980	.4192	3.950	688.0	344.0
5	14.172	8.65×10^{-2}	6250	.8451	7.970	1840.0	920.0
Aluminum-.50							
1	9.280	14.10×10^{-2}	10,200	*	*	*	*
2	3.045	4.63×10^{-2}	3360	.1423	1.158	112.0	56.0
3	4.860	7.39×10^{-2}	5370	.3882	3.160	288.0	144.0
4	6.173	9.38×10^{-2}	6820	.5442	4.420	464.0	232.0
5	4.110	6.25×10^{-2}	4540	.3568	2.900	205.5	102.7

Table 3

Specimen	Weight of Explosive in g.	$\frac{\text{Explosive wt. g.}}{\text{Specimen wt. g.}}$	V_o in/sec	W_{max}	W_{max}/H	λ	$\beta\lambda$
Steel-.75							
1	4.500	1.83×10^{-2}	1325	.0788	.742	76.3	57.2
2	7.380	3.00×10^{-2}	2180	.3283	3.100	206.7	157.0
3	8.960	3.64×10^{-2}	2640	.4047	3.800	302.0	226.0
4	14.395	5.85×10^{-2}	4240	.7106	6.710	783.0	587.0
5	16.180	6.59×10^{-2}	4790	.7911	7.460	995.0	745.0
Aluminum-.75							
1	4.330	4.38×10^{-2}	3190	.2592	2.110	110.5	83.0
2	7.095	7.17×10^{-2}	5200	.5536	4.510	268.0	201.0
3	11.750	11.90×10^{-2}	8640	*	*	*	*
4	8.250	8.35×10^{-2}	6060	.5577	4.540	366.0	274.0
5	6.560	6.56×10^{-2}	4830	.5132	4.180	233.0	174.0

Table 3

Specimen	Weight of Explosive in g.	$\frac{\text{Explosive wt. g.}}{\text{Specimen wt. g.}}$	V_o in/sec	W_{max}	W_{max}/H	λ	$\beta\lambda$
Steel-1.00							
1	5.985	1.83×10^{-2}	1320	.1670	1.578	76.3	76.3
2	9.755	2.97×10^{-2}	2160	.3908	3.690	202.0	202.0
3	12.405	3.79×10^{-2}	2760	.4577	4.310	330.0	330.0
4	17.795	5.43×10^{-2}	3950	.8454	7.970	678.0	678.0
5	22.595	6.89×10^{-2}	5000	.9869	9.320	1085.0	1085.0
Aluminum-1.00							
1	6.020	4.58×10^{-2}	3330	.3736	3.040	111.0	111.0
2	9.120	6.94×10^{-2}	5040	.6992	5.680	254.0	254.0
3	12.375	9.41×10^{-2}	6820	*	*	*	*
4	9.005	6.83×10^{-2}	4950	.6075	4.930	244.0	244.0
5	8.950	6.81×10^{-2}	4930	.6060	4.910	241.0	241.0

Table 3

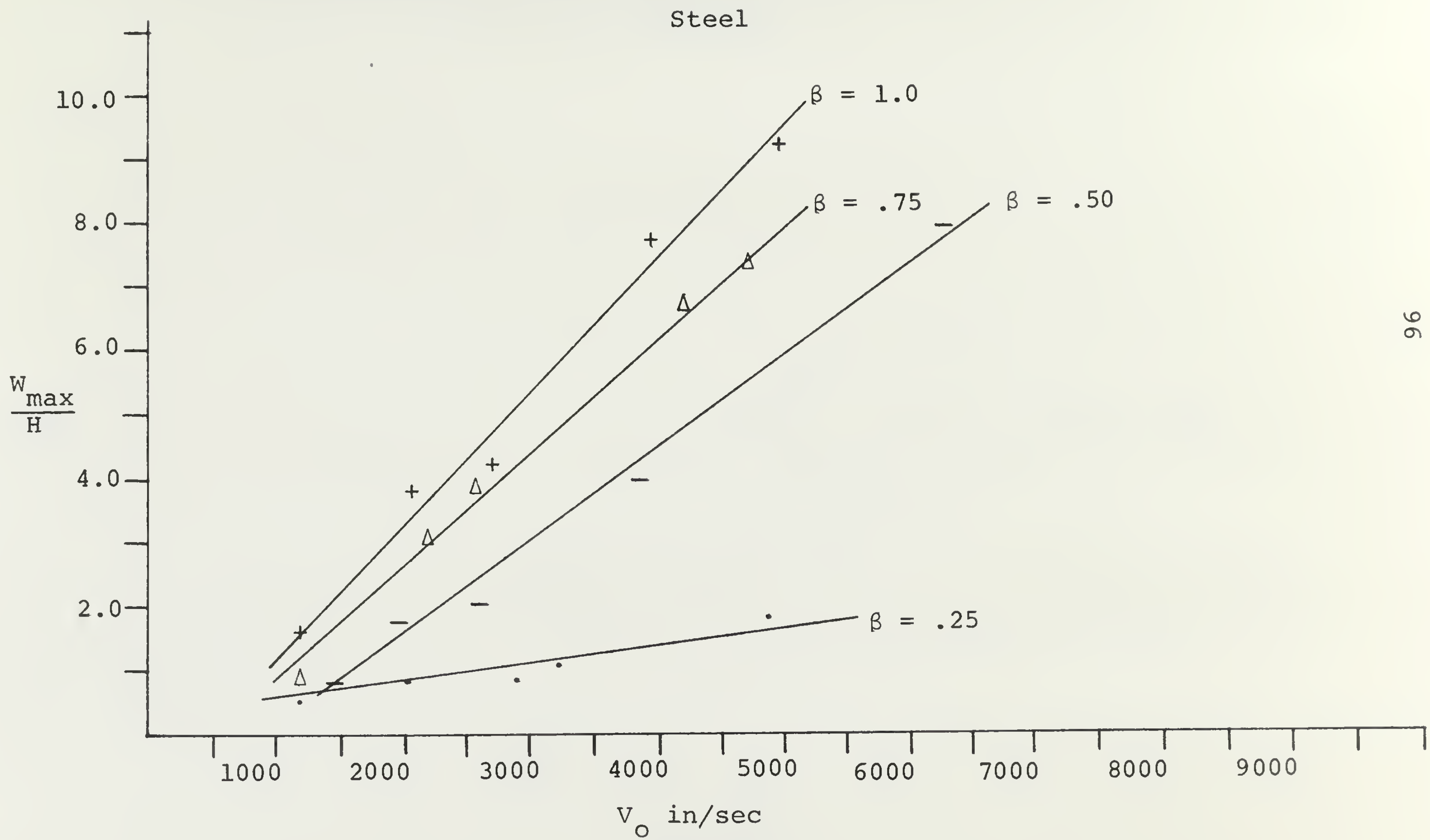

Steel
β = 1.0
β = .75
β = .50
β = .25
10.0
8.0
6.0
4.0
2.0
$\frac{W_{max}}{H}$
1000
2000
3000
4000
5000
6000
7000
8000
9000
V_o in/sec

Figure 16

Aluminum

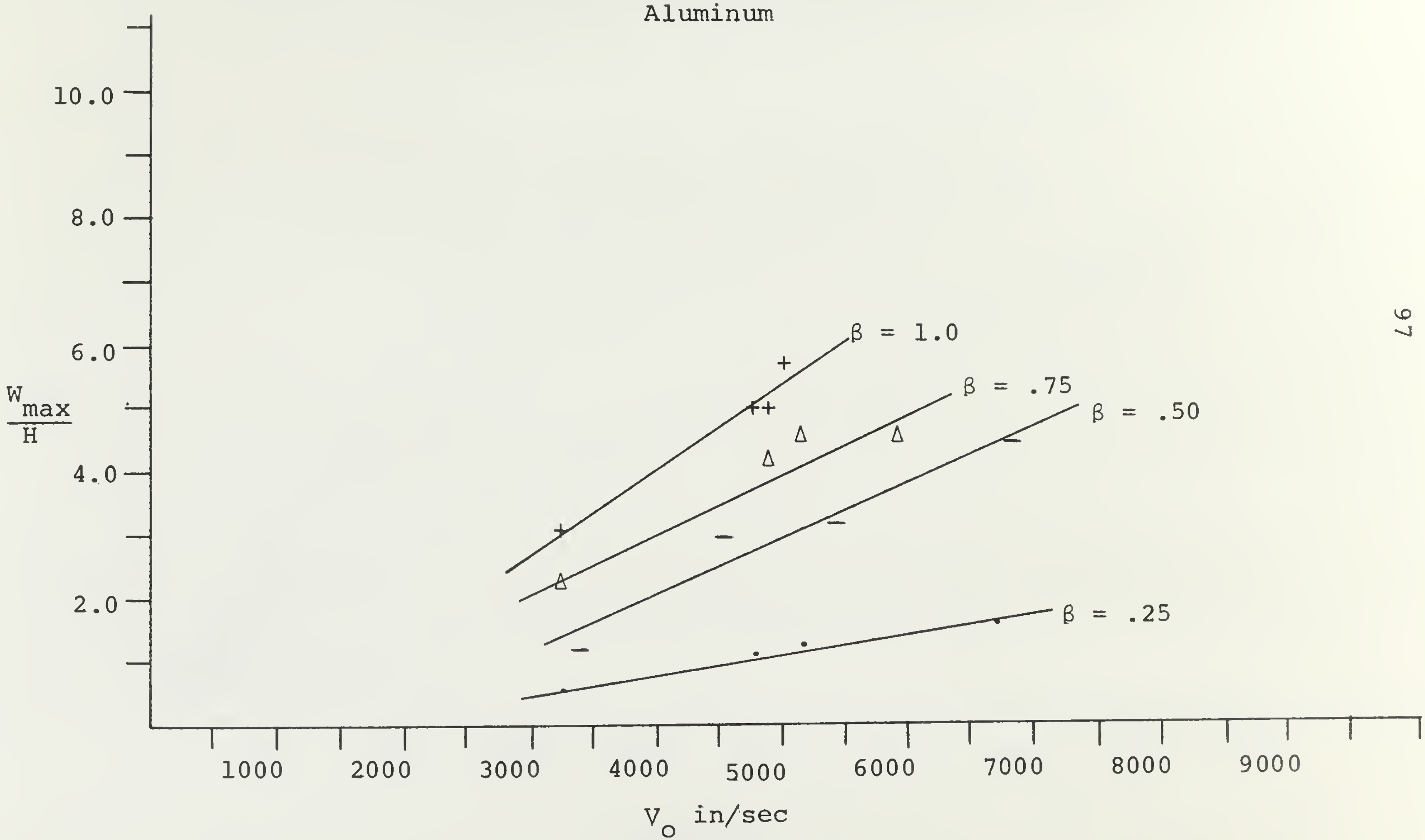


Figure 17

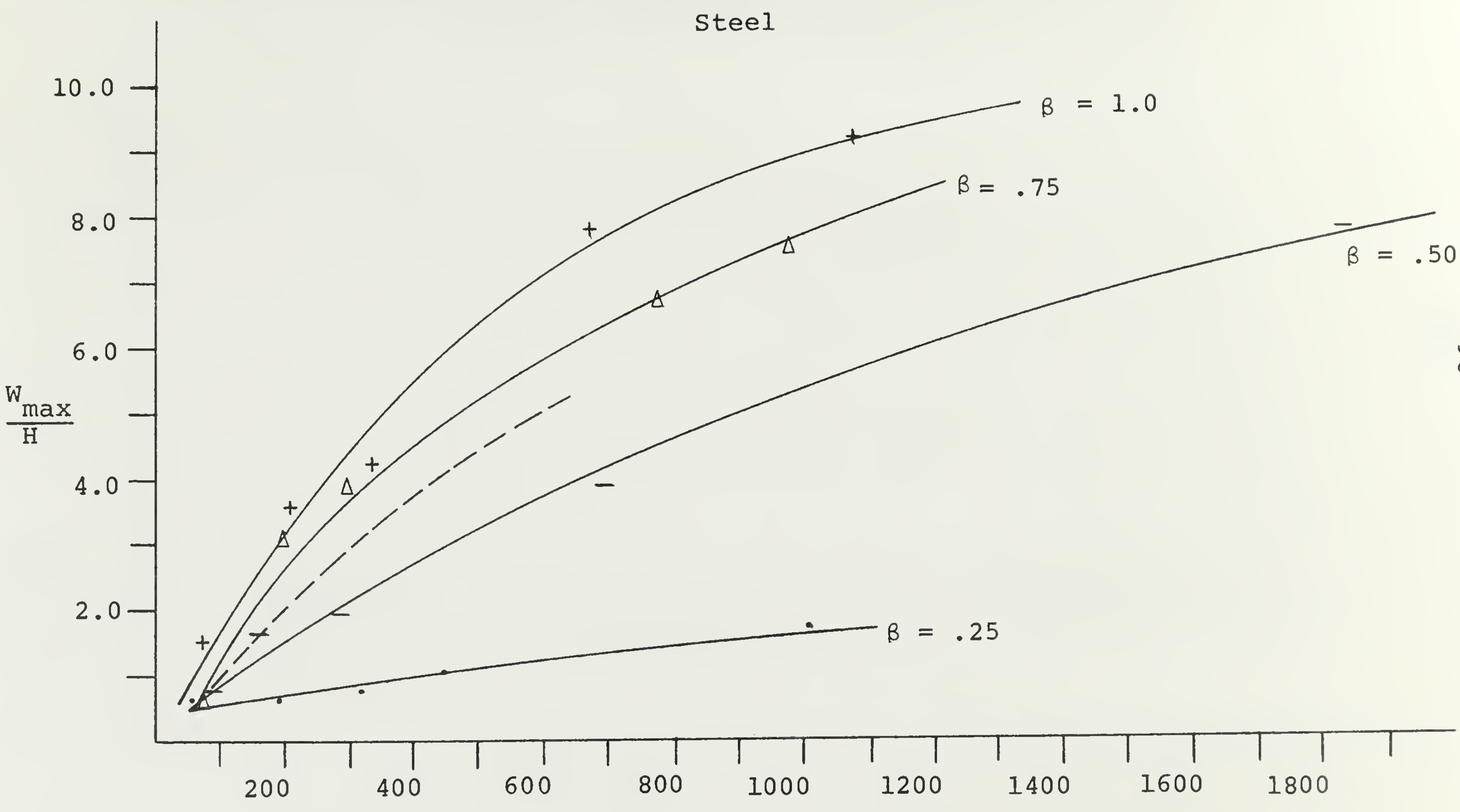

Steel
10.0
8.0
6.0
4.0
2.0
$\frac{W_{max}}{H}$
β = 1.0
β = .75
β = .50
β = .25
200
400
600
800
1000
1200
1400
1600
1800
λ

Figure 18

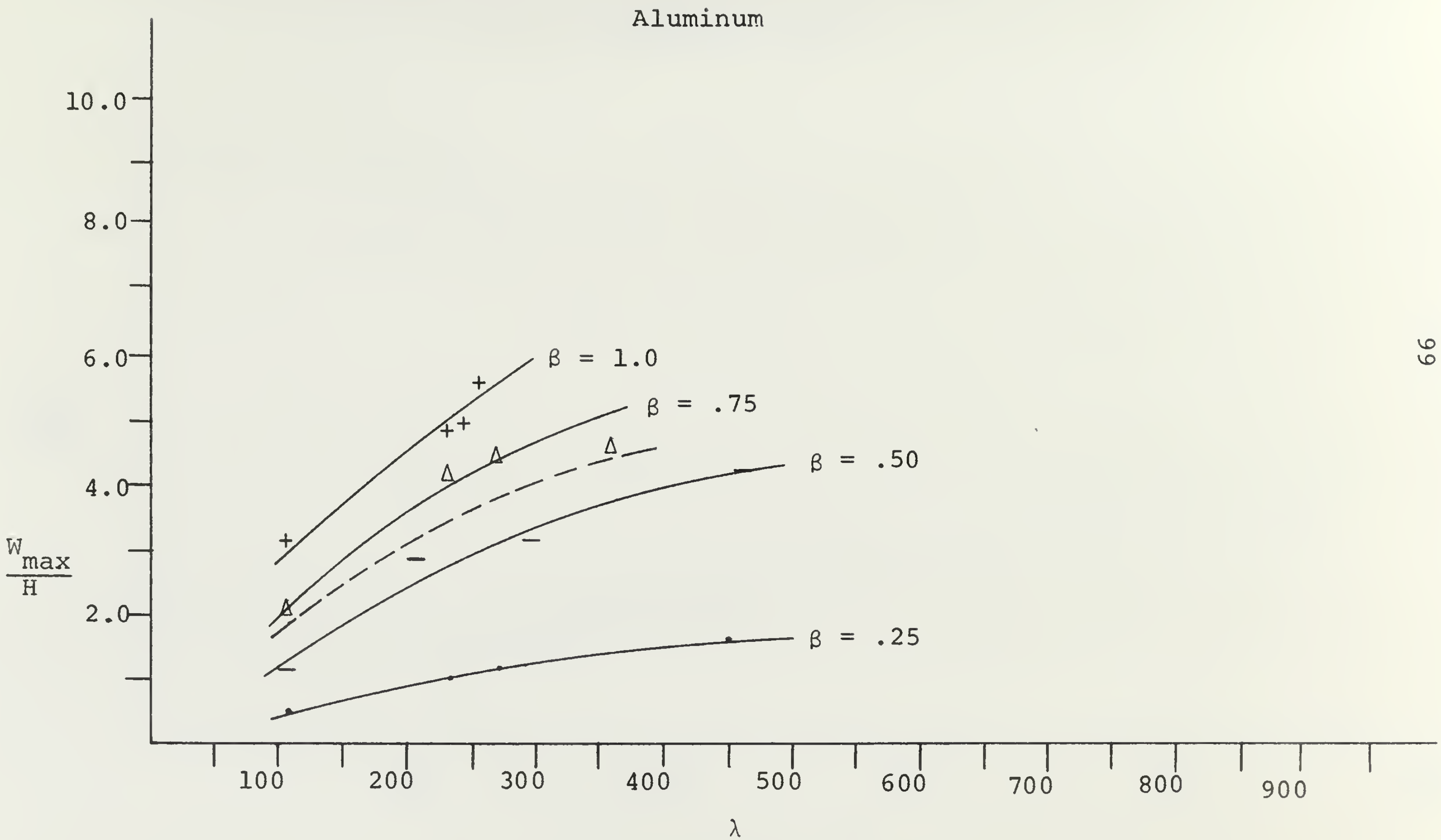

Aluminum
10.0
8.0
6.0
4.0
2.0
$\frac{W_{max}}{H}$
β = 1.0
β = .75
β = .50
β = .25
100
200
300
400
500
600
700
800
900
λ

Figure 19

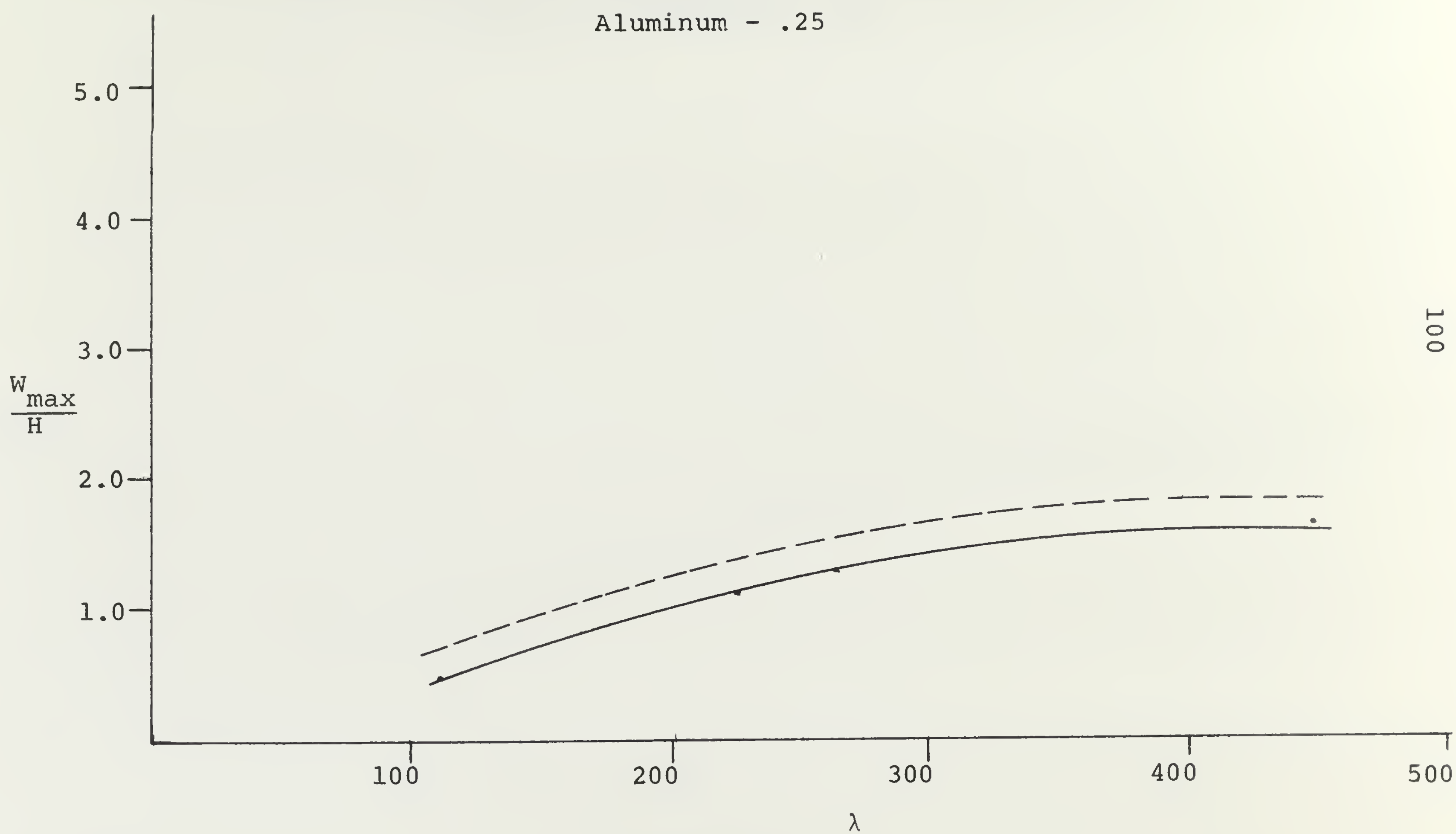


Figure 20

Aluminum - .50

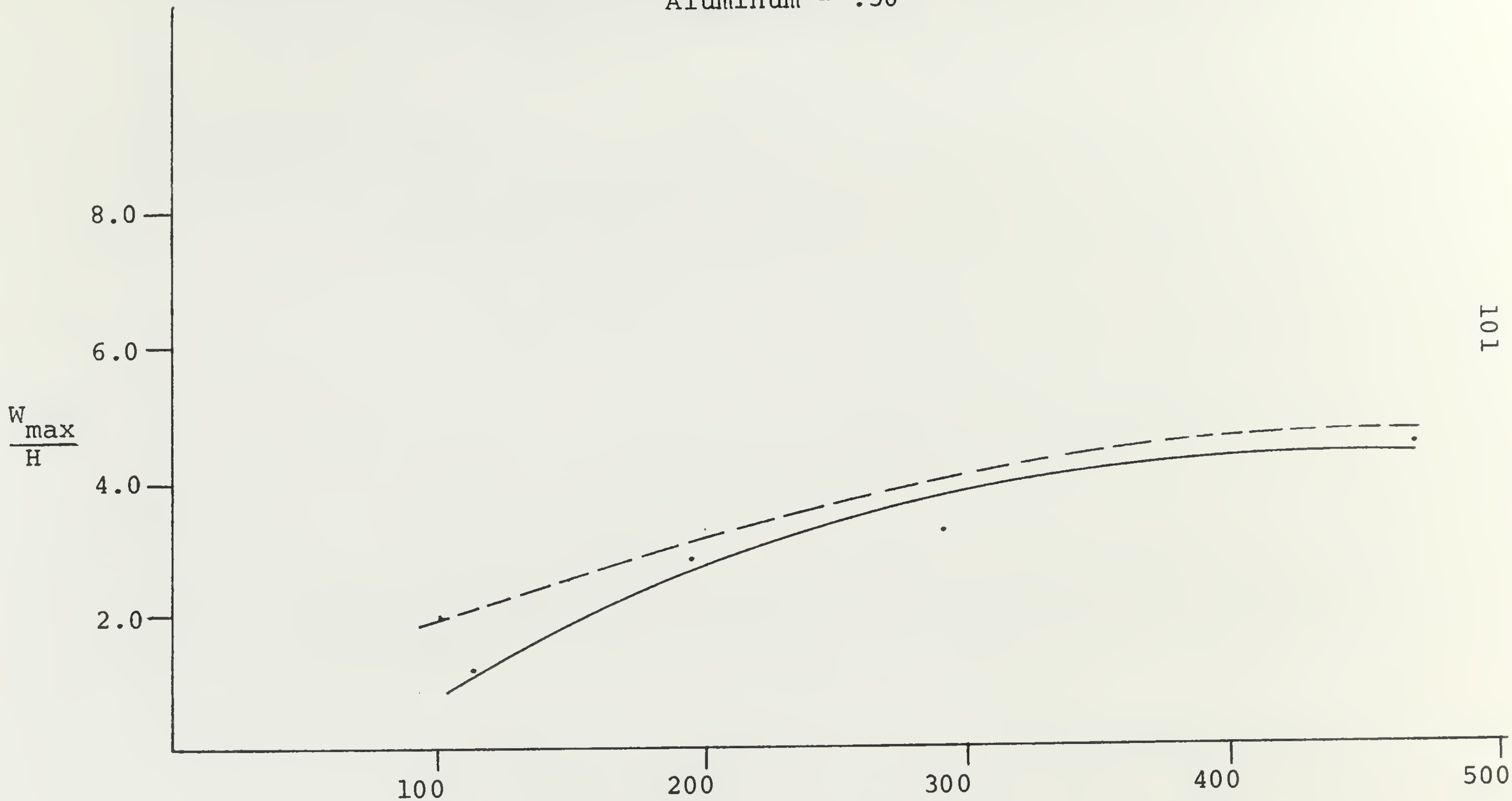


Figure 21

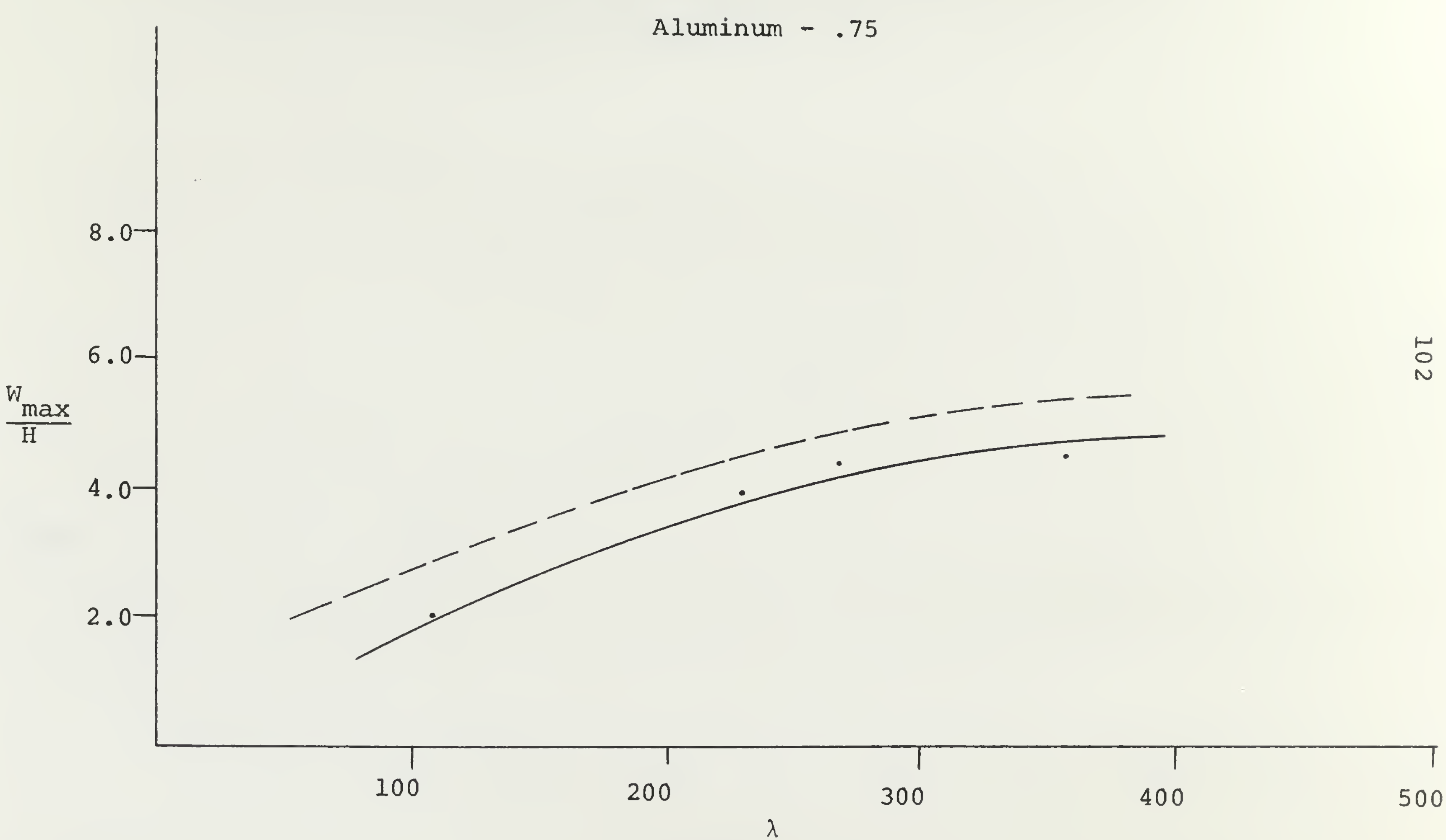


Figure 22

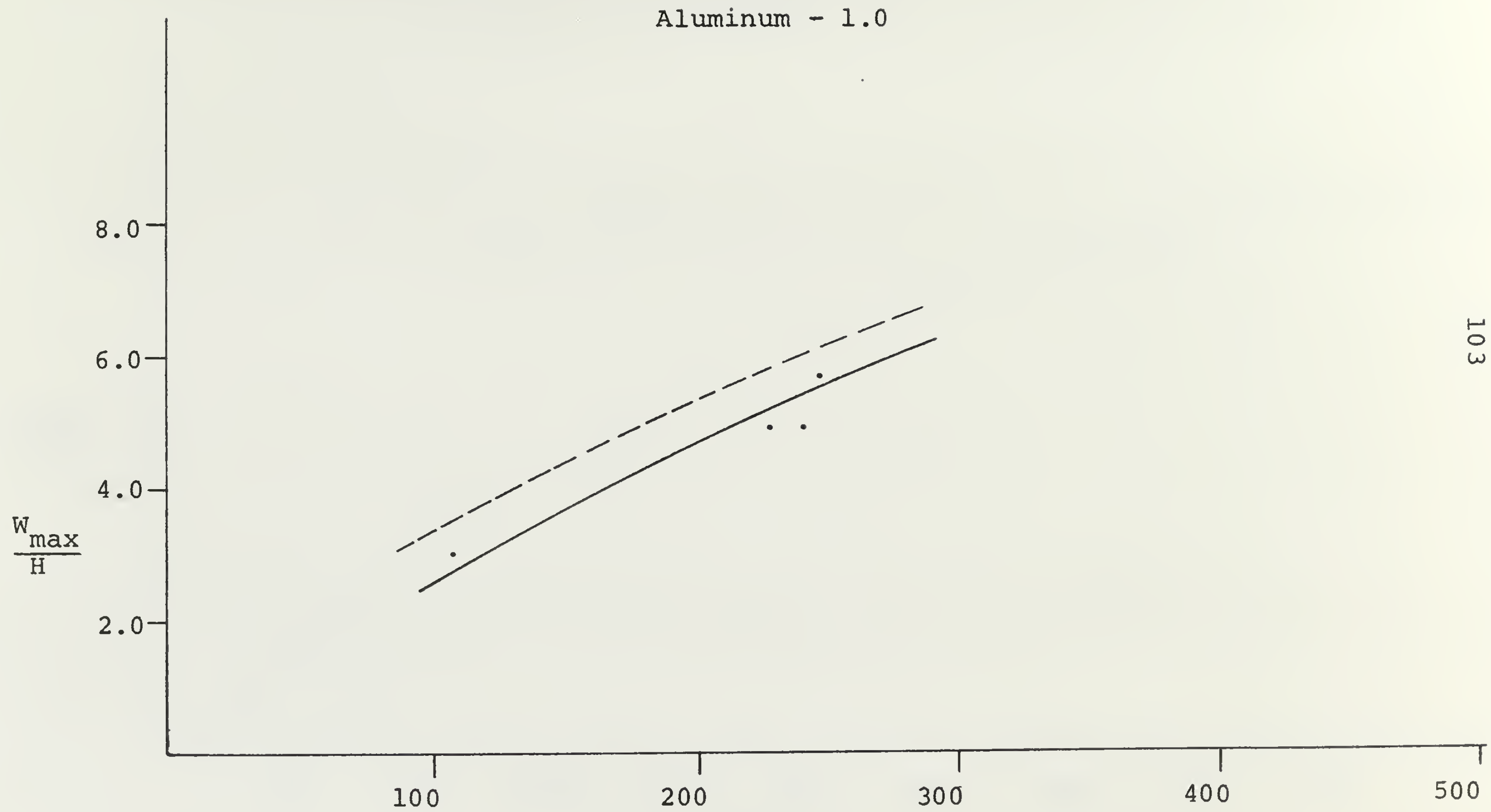


Figure 23

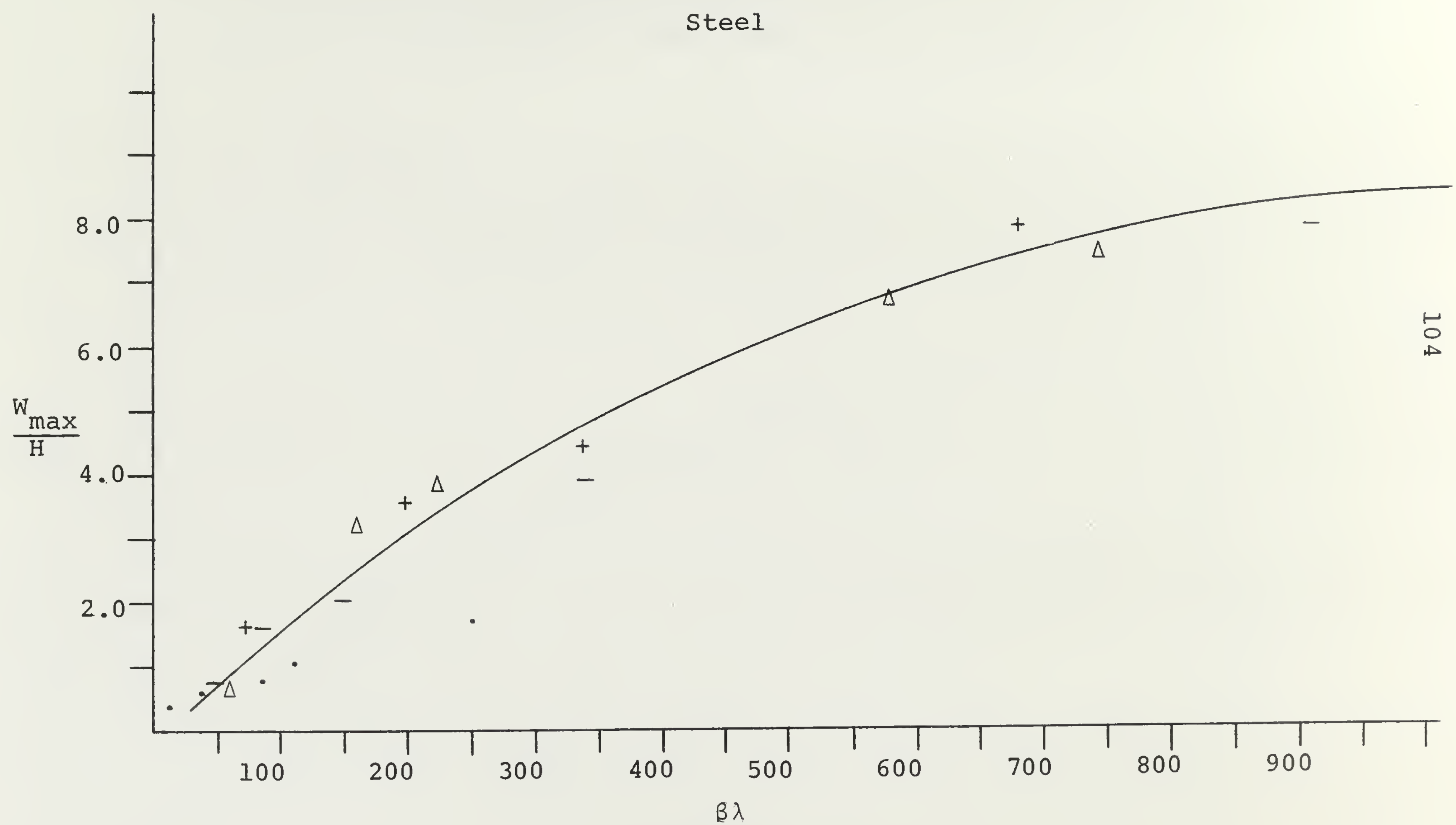

Steel
8.0
6.0
4.0
2.0
$\frac{W_{max}}{H}$
100
200
300
400
500
600
700
800
900
βλ

Figure 24

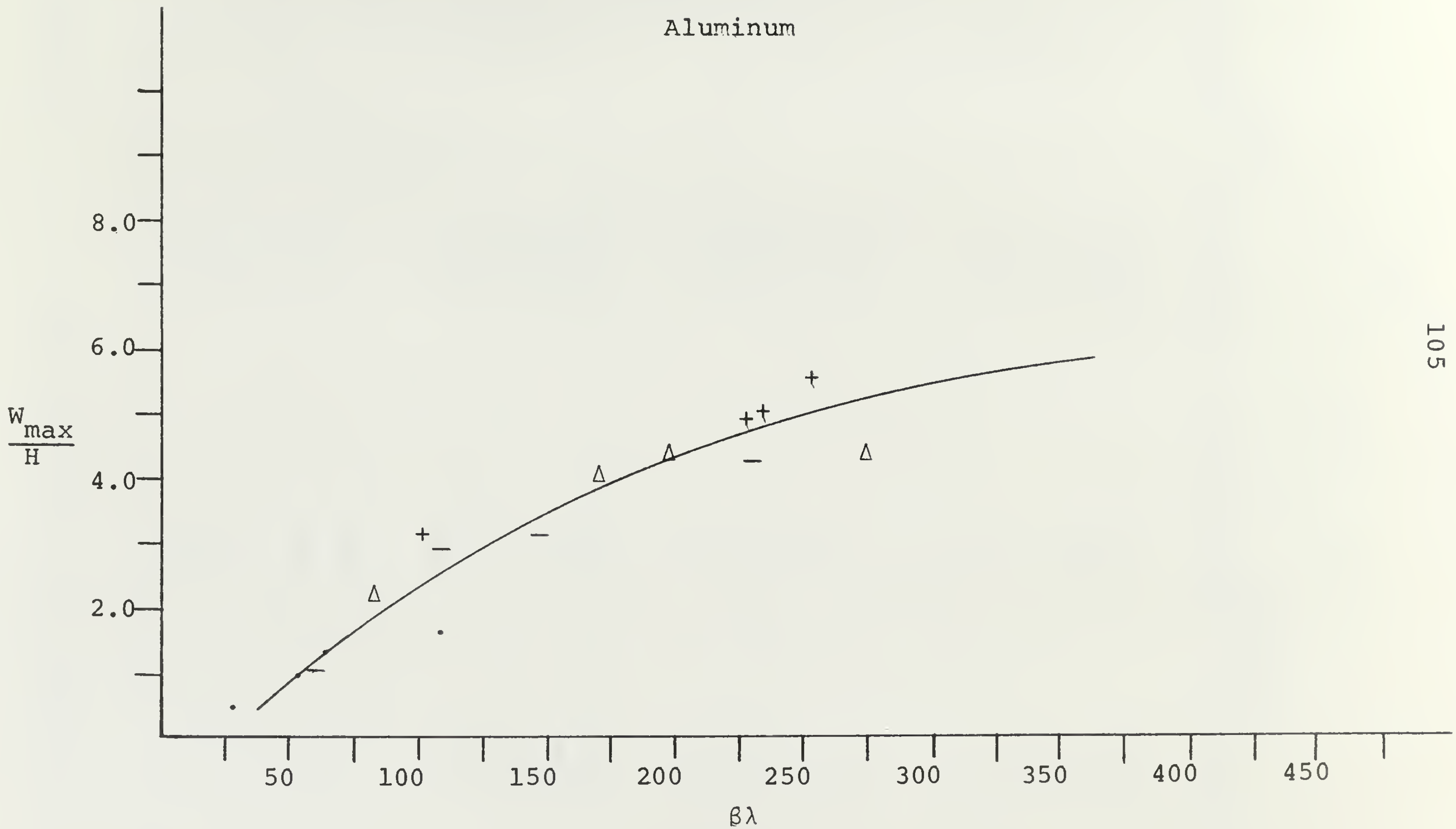


Figure 25

Table 4

$$\phi = \tan^{-1} \{(3 + \beta^2)^{1/2} - \beta\}$$

	Steel		Aluminum	
	Observed Angle	Calculated ϕ	Observed Angle	Calculated ϕ
β = .25				
1	*	56.2°	*	56.2°
2	*	56.2°	56°	56.2°
3	56°	56.2°	54°	56.2°
4	54°	56.2°		56.2°
5	56°	56.2°	56°	56.2°
β = .50				
1	*	52.4°		52.4°
2	53°	52.4°	52°	52.4°
3	51°	52.4°	51°	52.4°
4	51°	52.4°	51°	52.4°
5	52°	52.4°	51°	52.4°
β = .75				
1	*	48.5°	47°	48.5°
2	49°	48.5°	48°	48.5°
3	48°	48.5°		48.5°
4	48°	48.5°	49°	48.5°
5	47°	48.5°	49°	48.5
β = 1.00				
1	*	45.0°	45°	45.0°
2	45°	45.0°	45°	45.0°
3	45°	45.0°		45.0°
4	45°	45.0°	45°	45.0°
5	45°	45.0°	45°	45.0°

* Non-descript

Space indicates total separation

APPENDIX E

RESULTS OF THE PENDULUM

The impulse initiated by the explosion of the DETASHEET supplies direct and rotational impulse. The pendulum swing θ_m can then be measured by calculating the tan θ_m from the heat sensitive paper track over the swing from suspension to the pen tip. The velocity of the pendulum at mid-swing can be calculated by the equation balancing the maximum potential and kinetic energy. The inital velocity V_o can be calculated by a momentum balance.

D = the perpendicular distance from the suspension point to the center of gravity of the pendulum.

g = acceleration due to gravity.

L_s = the perpendicular distance from the suspension point to the center of gravity of of the specimen.

R = perpendicular distance from pendulum suspension point to needle tip.

s = pendulum track length

W = the total weight of the pendulum and the specimen.

W_s = the weight of the specimen (the part of the specimen plate not under the clamps).

θ_m = the maximum angle through which the pendulum swings.

The equation developed comes from [12]

$$V_o = \frac{\sqrt{\{2g(WD^2 + W_s L_s^2)D(1 - \cos\theta_m)W\}}}{W_s L_s}$$

D = 121.6 in

g = 32.2 ft./sec.^{2}

L_s = 122.0 in

R = 126.3 in

W = (Pendulum Wt. + Specimen Wt.)
W = {pendulum wt. + clamps wt. + ballast blocks wt. + ballast clamps wt. + (bolts-nuts-washers)wt. + specimen plate wt.}
W = {46.40 lbs. + 35.80 lbs. + 17.95 lbs. + 1.13 lbs. + total specimen plate wt.}
W = {104.51 lbs. + total specimen plate wt.}

W_s = specimen wt. (not within the clamps)
$W_s = (2B)(2L)(H)(\rho)$
ρ was determined by the water displacement method.
ρ = .2723 lbs/in^3 mild steel
ρ = .0544 lbs/in^3 aluminum
B = semi-width of specimen
L = semi-length of specimen
H = thickness

θ_m comes from:

$$\theta_m = \frac{s}{R} = \left(\frac{360}{2\pi}\right)\frac{\text{track}}{(R)} \text{ degrees}$$

$$\theta_m = \frac{s}{R} \text{ radians} = \left(\frac{180}{\pi}\,\frac{s}{126.3}\right)\text{degrees}$$

SAMPLE CALCULATION

Specimen - .25 - #4 Wt. of Explosive = 5.470 g. W_s = .181 lbs.

$$V_o = \frac{\sqrt{\{(2)(32.2)(106.61(121.6)^2 + (.181)(122.0)^2)(121.6)(1 - \cos\theta_m)(106.61)\}}}{(.181)(122.0)}$$

$$s = 4.120 \text{ in}$$

$$\theta_m = \left(\frac{360}{2\pi}\right)\left(\frac{4.120}{126.3}\right) = 1.86°$$

$$\theta_m = 1.86°$$

$$\cos\theta_m = \cos 1.86° = .99951$$

$$V_o = 3990 \text{ in/sec}$$

Figure 26

PENDULUM RESULTS

Specimen	Track (in)	θ_m°	cos θ_m	Pendulum V_o in/sec	Calibration V_o in/sec
S-.25-1	2.062	.940	.99986	2120	1325
2	2.531	1.145	.99980	2540	2110
3	2.625	1.191	.99978	2660	2730
4	4.120	1.869	.99951	3990	4820
5	2.875	1.305	.99974	2905	3200

Table 5

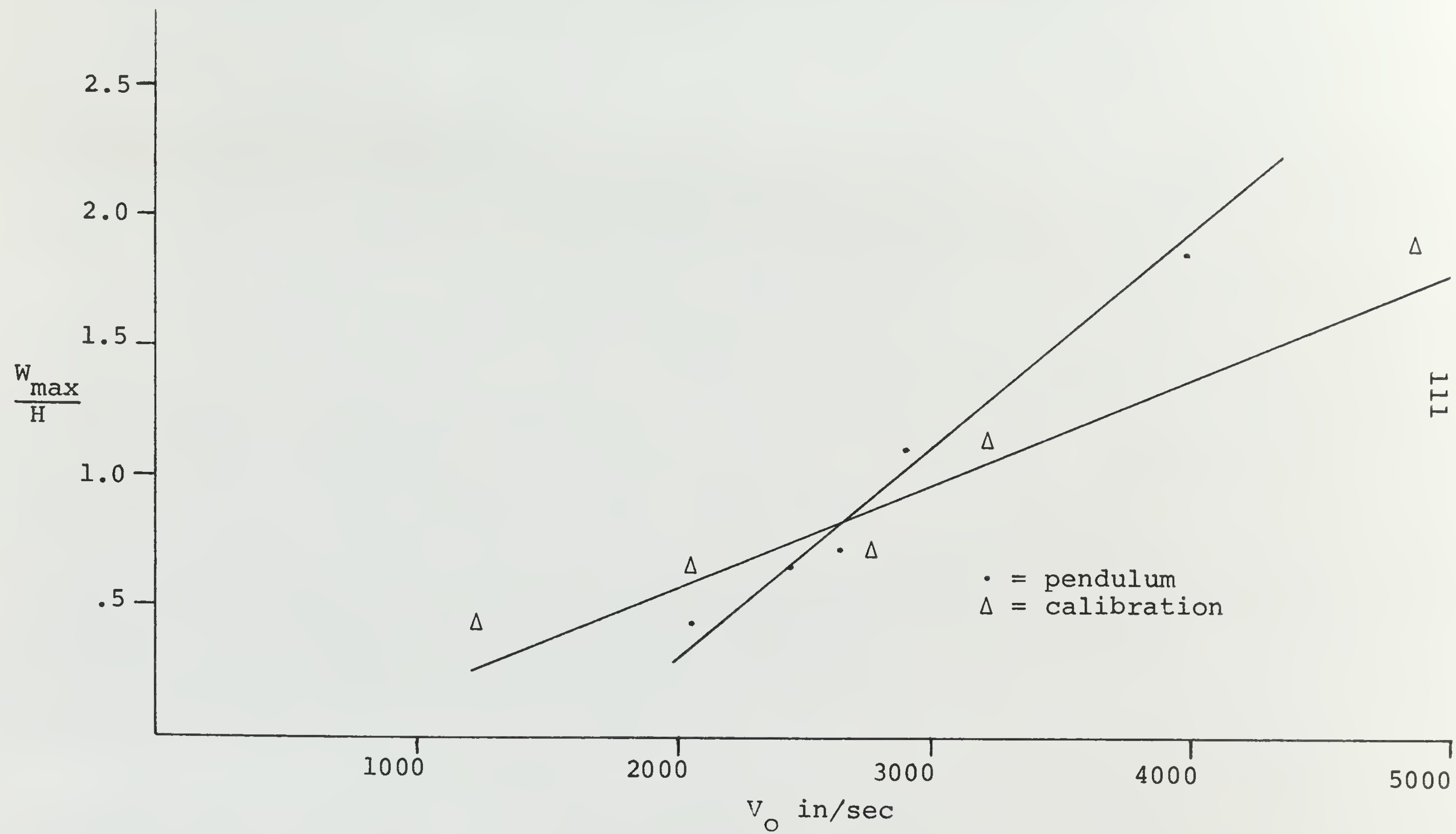

2.5
2.0
1.5
1.0
.5
$\frac{W_{max}}{H}$
1000
2000
3000
4000
5000
V_o in/sec
· = pendulum
Δ = calibration

Figure 27

Thesis 127227
B127 Baeder
Investigation of the plastic behavior of fully clamped rectangular plates under dynamic loading.